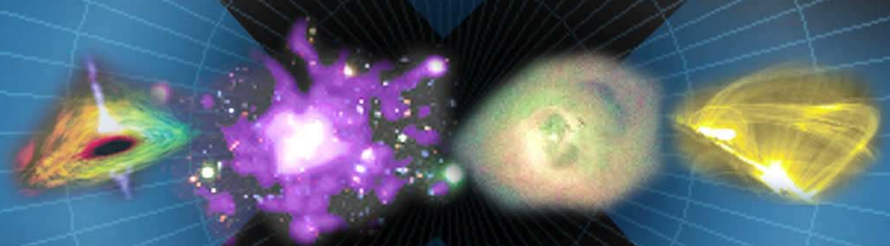
Constellation
The Constellation X-Ray Mission



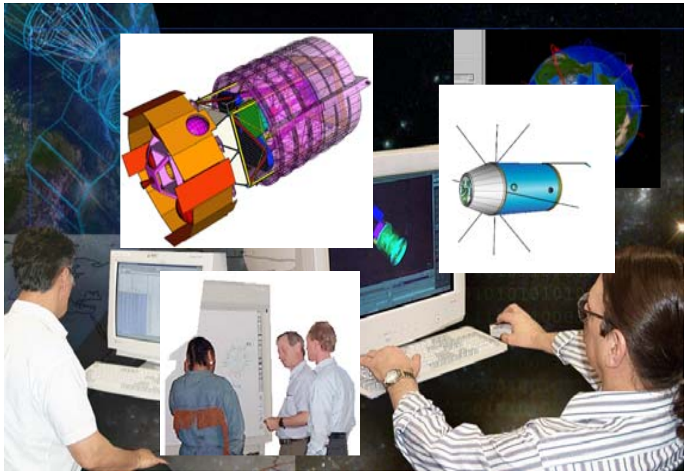
Constellation-X Atlas Single Launch Observatory Configuration

Presented by
Gabe Karpati, MSE (GSFC)

Facility Science Team Meeting (FST)
December 18 – 20, 2006/Goddard Space Flight Center

Atlas V Single Launch Configuration Study

- A study was completed at GSFC's Integrated Mission Design Center (IMDC) during the first week of December to define the Con-X Observatory configuration for the Atlas V Single Launch Mission
- Payload Complement:
  - Four 1.3 m SXT Mirrors
  - Four XMS Instruments
  - Science Enhancement Package (SEP)
    - Assumed 200 kg hardware on the Observatory to accommodate two SEP concepts
- Complete Payload Accommodation Requirements are in the Backup Material

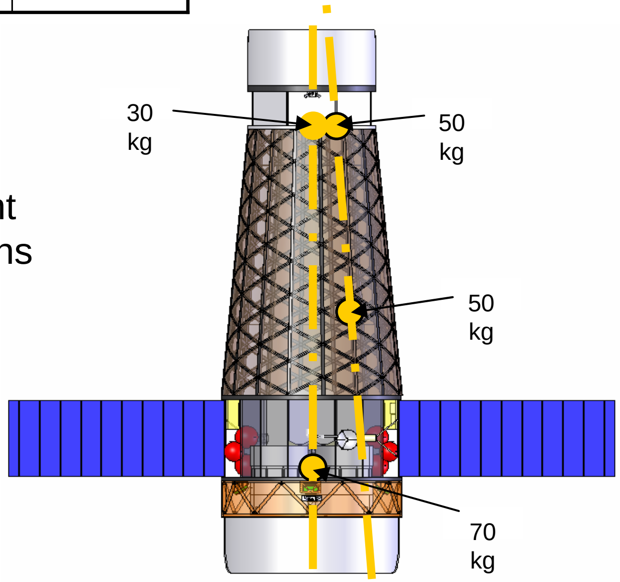


SEP Accommodation Requirements

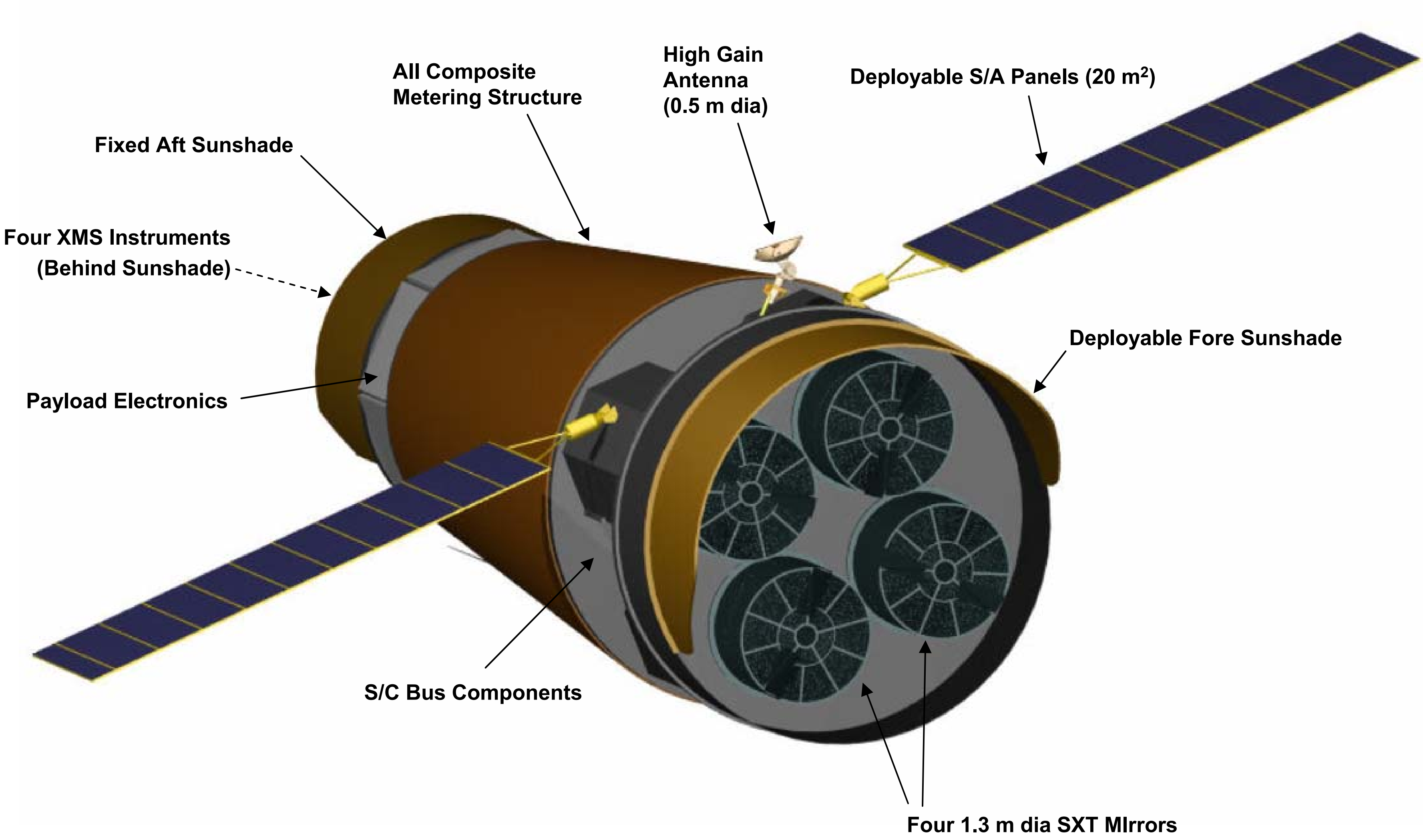
SEP Part 1 of 2			
	Optic	Detector	Electronics
Location	Optical bench, center or outside SXTs, but as close to center as possible	Focal plane, boresight aligned to optic	Focal plane, nearby detector
Volume	Consider as point masses		
Mass	70 kg	30 kg	
Power (peak)	n/a	15W	
Power (avg)	n/a	15W	
Data rate (peak)	n/a	150 kbps	
Data rate (avg)	n/a	13 kbps	
Thermal (operating)	20 +/- 0.5C	-20 to -5C (Detector) -50 to +10C (housing)	-30 to +30C
Thermal (survival)	+10 to +30C	-40 to +40 C (detector) -50 to +40C (housing)	-50 to +30C

SEP Part 2 of 2			
	Optic	Detector	Electronics
Location	Between optical bench and focal plane at 1/3 point – closer to focal plane, within one of the SXT beams	Focal plane, between the XMS detector and the center of the focal plane	Focal plane, nearby the detector
Volume	Consider as point masses		
Mass	50 kg	50 kg	
Power (peak)	n/a	30W	
Power (avg)	n/a	30W	
Data rate (peak)	n/a	867 kbps	
Data rate (avg)	n/a	67 kbps	
Thermal (operating)	20 +/- 0.5C	-80 to -60C	-5 to +25C
Thermal (survival)	+10 to +30C	-100 to +30 C	-65 to +40C

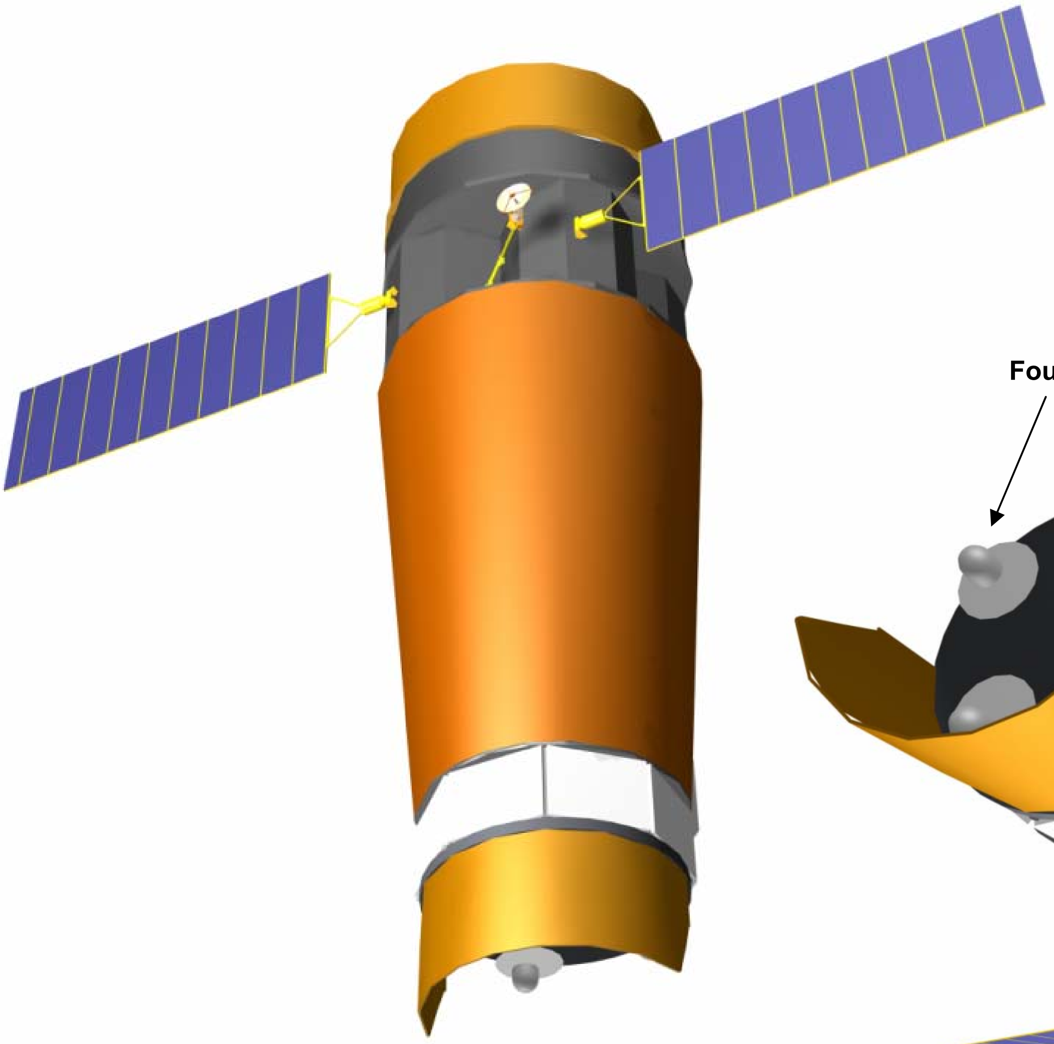
SEP modeled as point masses at four locations

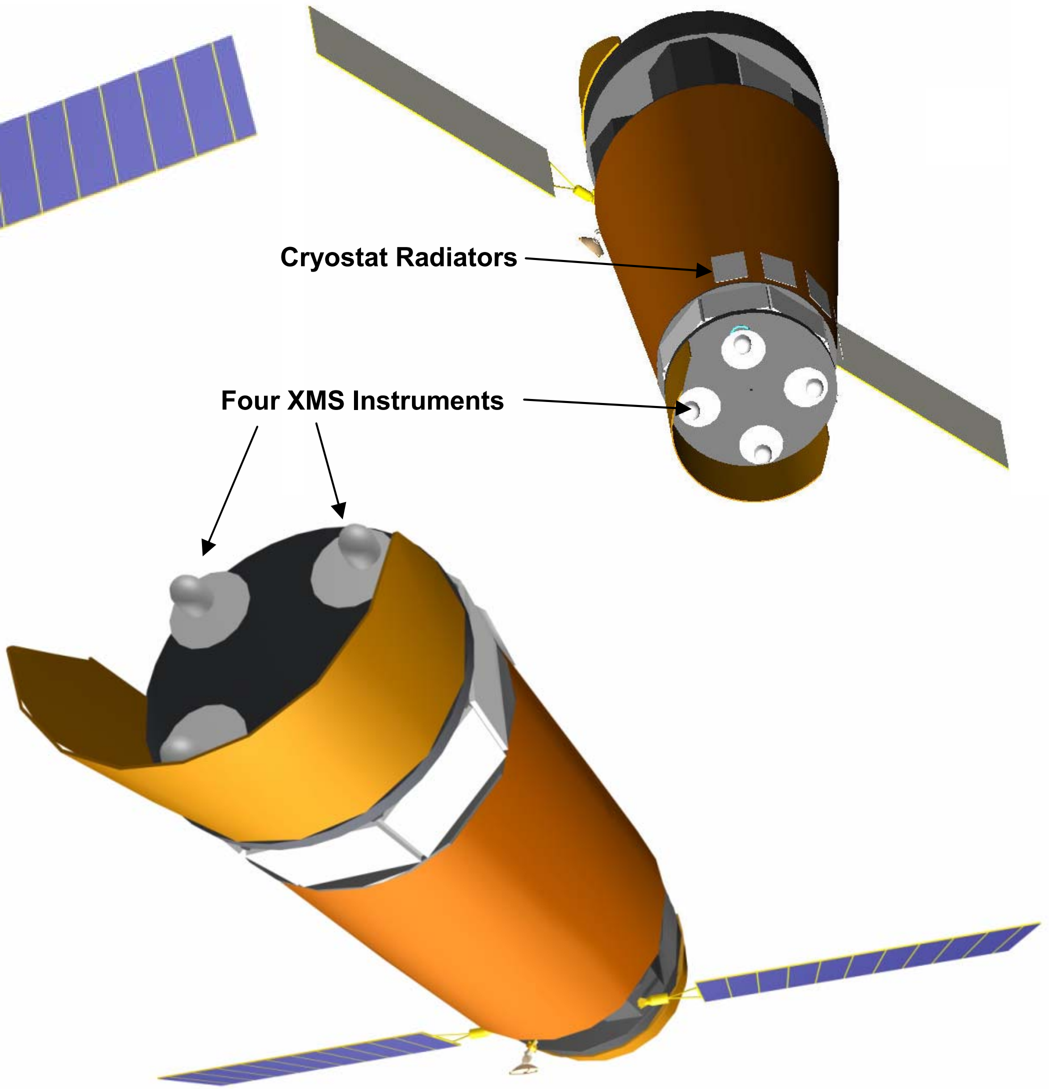


Constellation-X Atlas V Single Launch Observatory

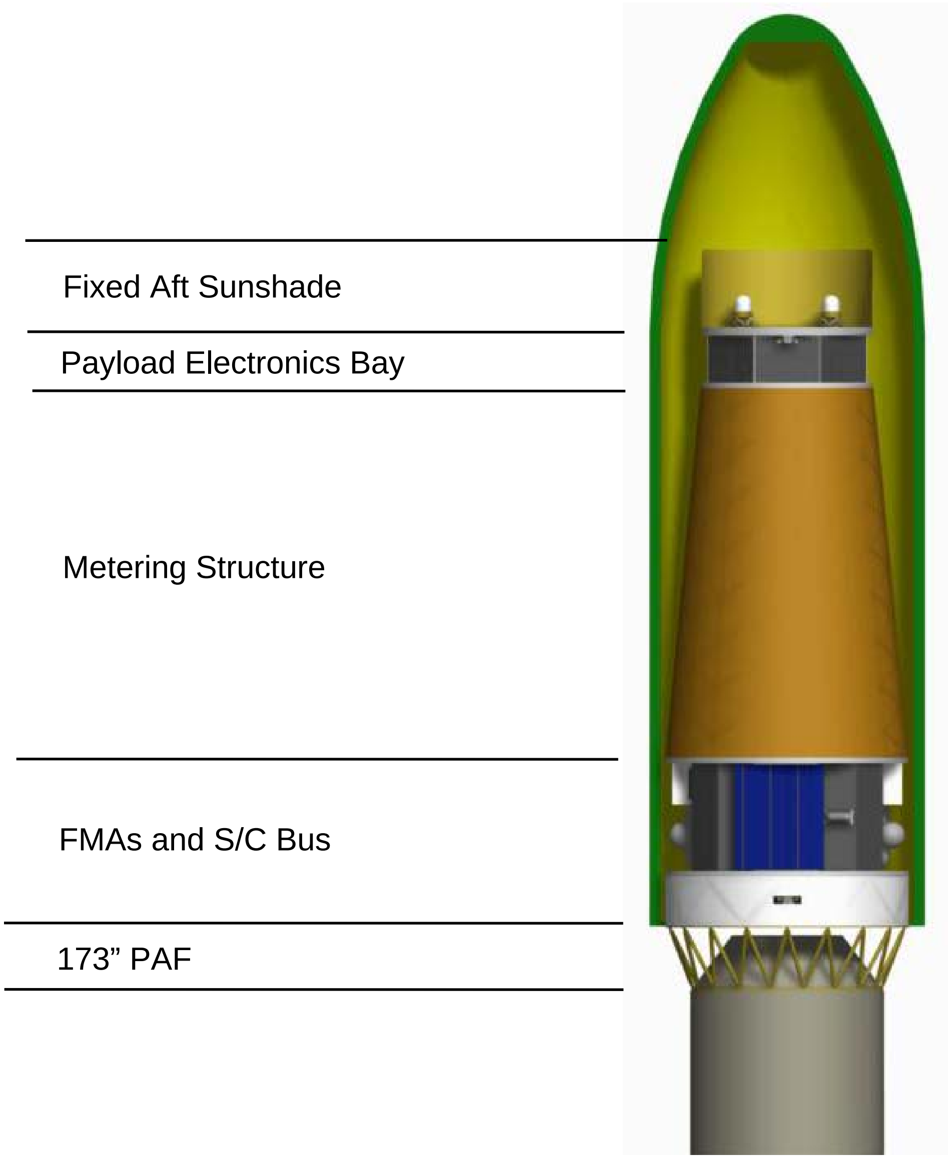


Observatory Sun and Anti-Sun Views



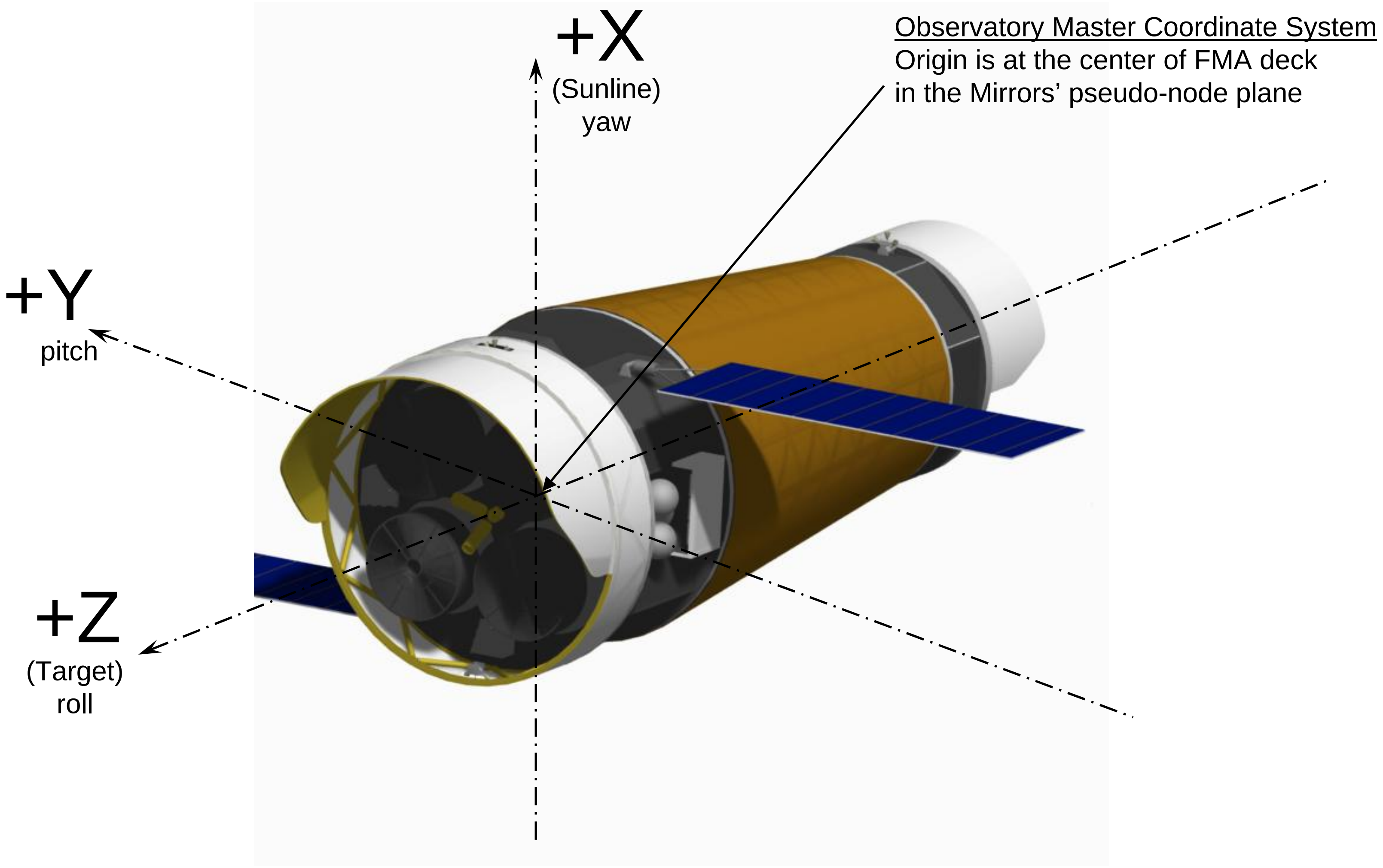


Observatory Launch Configuration

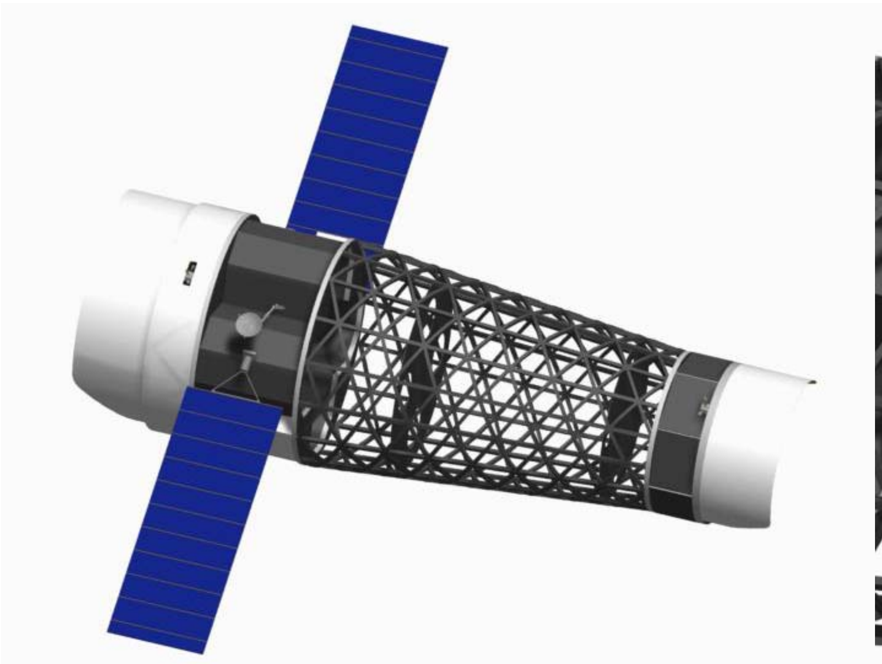


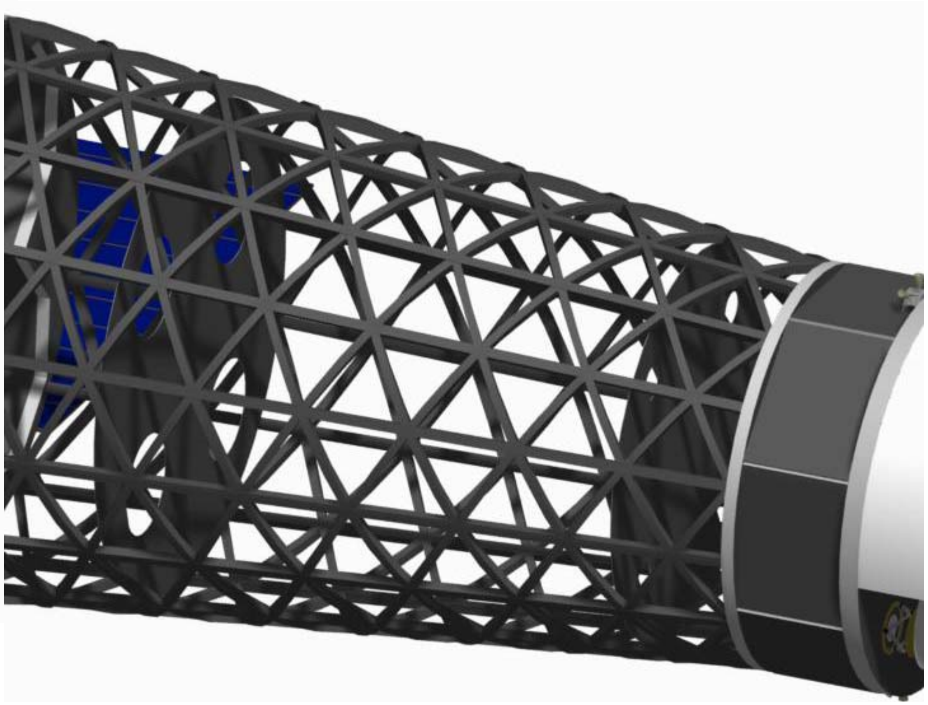
Atlas V 551
Long Fairing

Observatory Master Coordinate System Defined



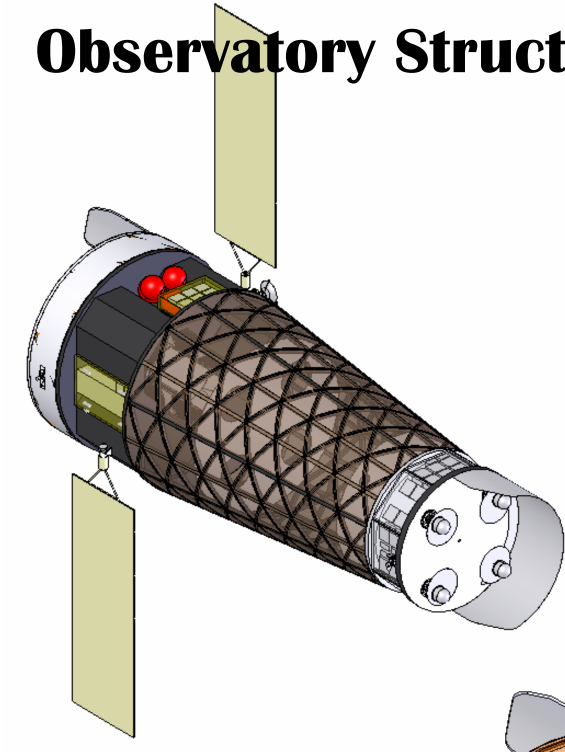
Advanced Composite Structure

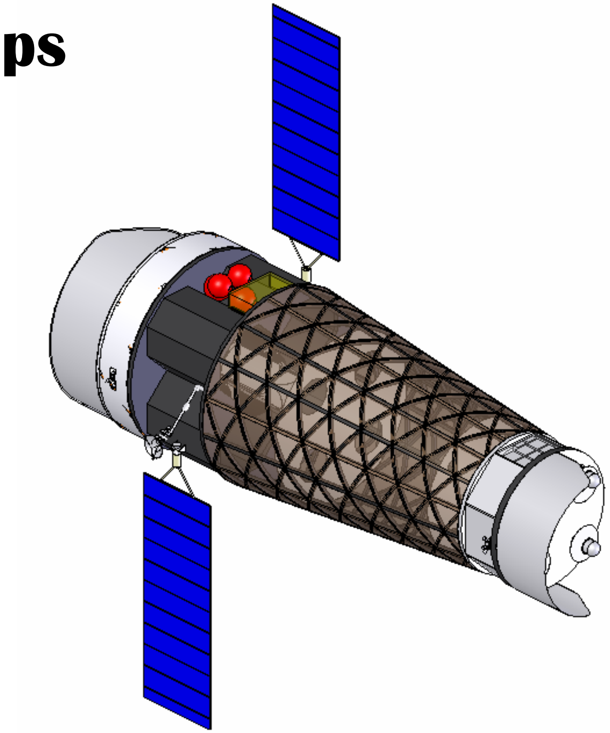




- Metering structure is composite isogrid construction.
- This type of construction has been used for the Boeing Starliner (787) and the AFRL has been developing a payload fairing for the Minotaur launch vehicle

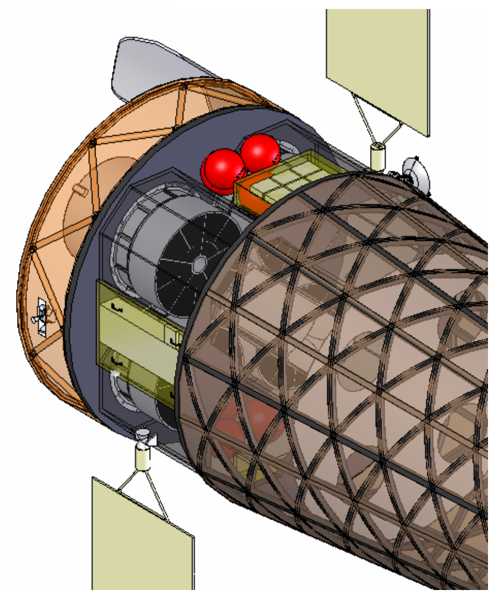
Observatory Structure Close-ups

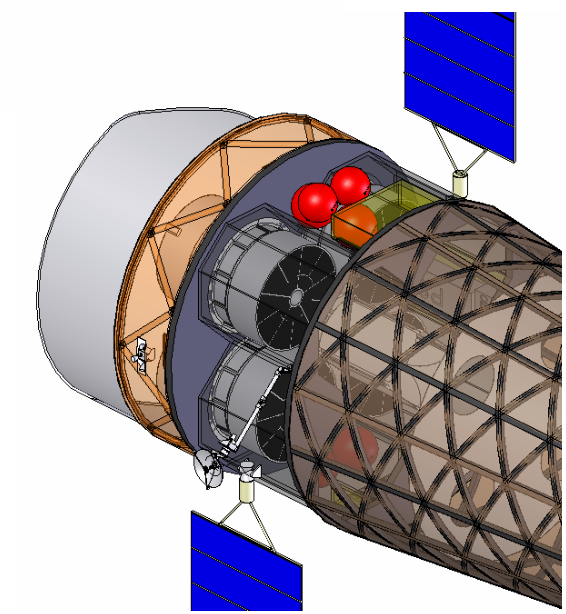




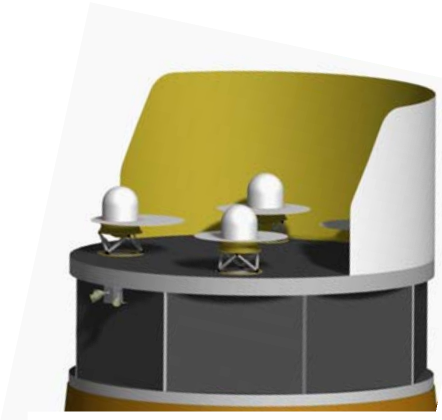
Sun Side

Anti-Sun Side



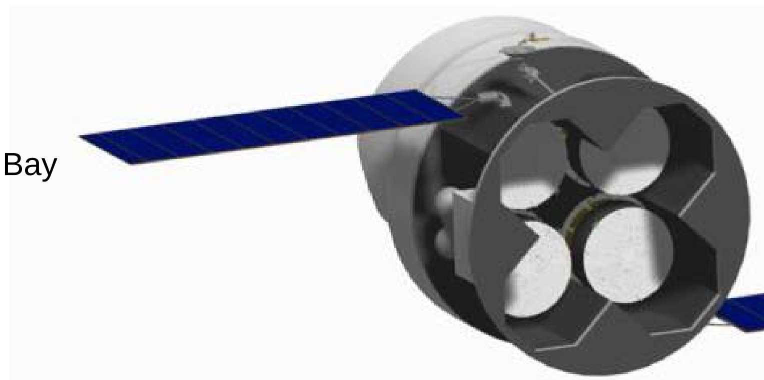


Observatory Details Close-ups

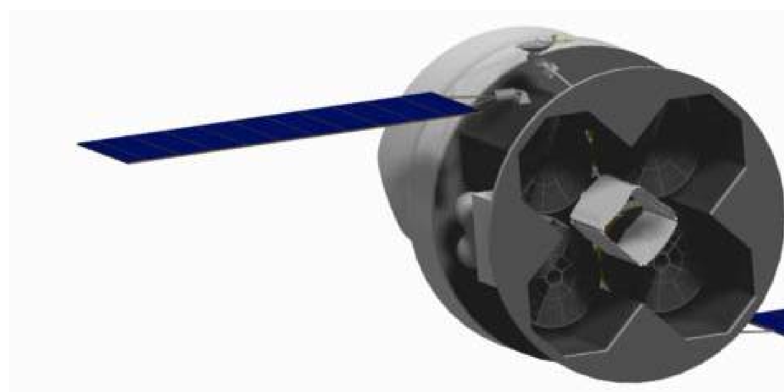


Detector End
- Fixed Sunshade
- XMSs mounted on Focus Mechanism Platforms
- Payload Electronics Bay

Post-Collimator Cover Retraction
View from rear w/ Metering Structure removed



Before Retraction

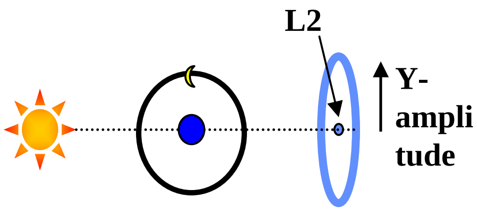


After Retraction

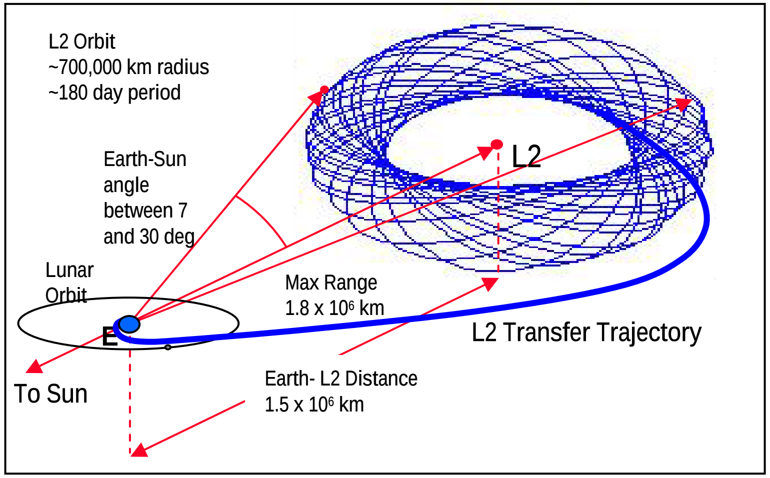
Payload Electronics Bay
Cutaway view from rear w/ XMSs and Detector Deck removed: Electronics Boxes mounted to individual “Radiator Panels grouped by XMA

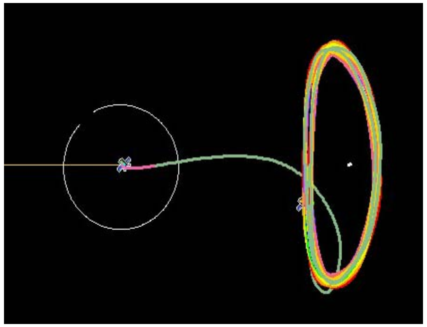
Mission Overview

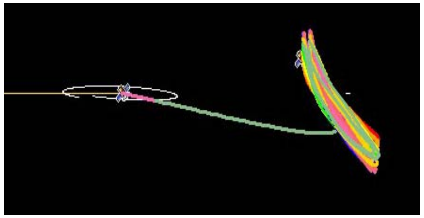
- **Launch Vehicle: Atlas V**
  - Atlas V 551 Long Fairing (5 m dia x 26.5 m tall)
  - Throw Mass: 6305 kg @ C3 = -0.5 kg^2/s^2
- **Launch**
  - Launch from KSC on 3/21/2017
  - Direct "zero delta-v" insertion into L2 halo orbit w/ 800,000 km Y amplitude
  - ~ 100 day cruise phase
  - Orbit Amplitude Lowering Maneuver upon arrival to L2 to 700,000 km (delta-v = 25 m/s)
- **Mission Life**
  - Mission Life: 5 years required, 10 years goal



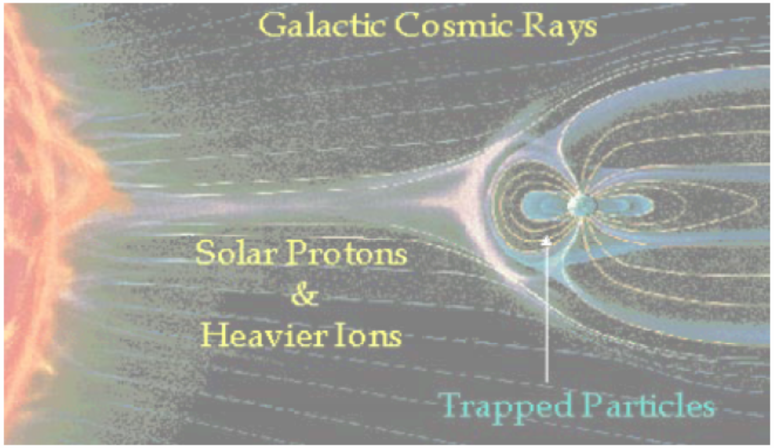
Courtesy - JWST

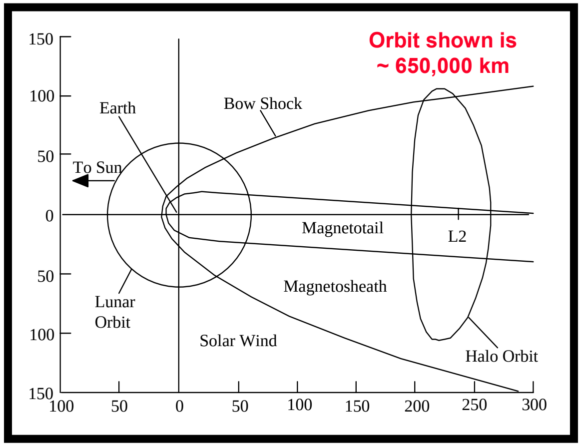






Orbit vs. Earth's Magnetosphere

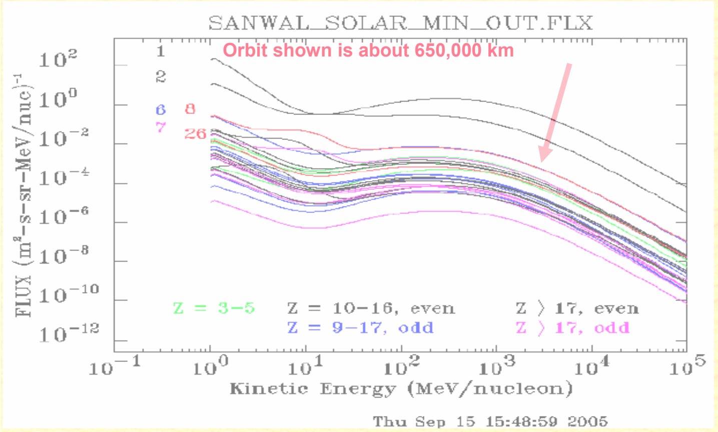




- Geomagnetic shielding at the ISS orbit reduces solar event proton flux by over 3 orders of magnitude, compared to free solar wind
- Lesser but still significant geomagnetic shielding effect exists at L2 within the Magnetosheath

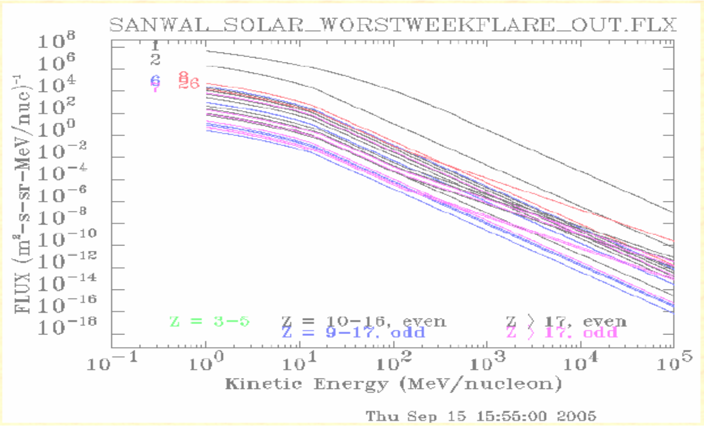
Solar Minimum

Total proton flux = 4.69/cm²/s



Average of Worst Week Solar Flare

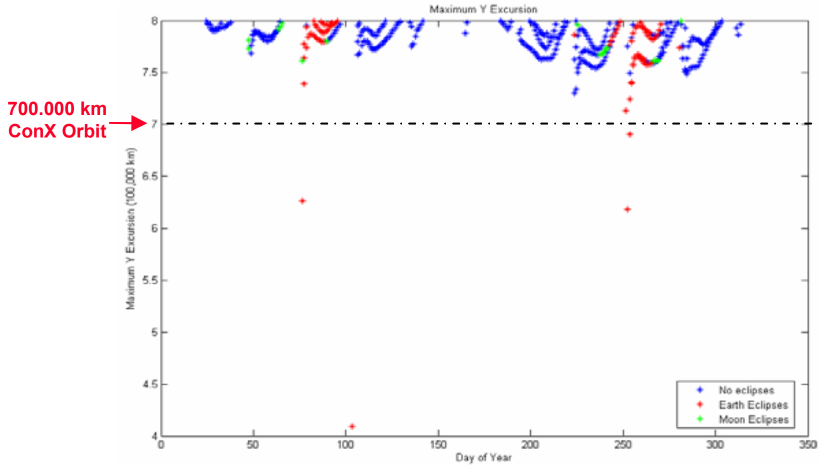
Total proton flux ~ 143000/cm²/s

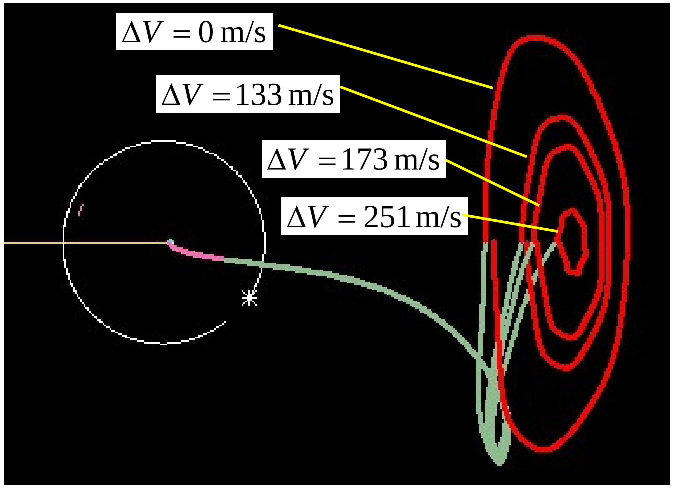


Launch Opportunities vs. Orbit Amplitude

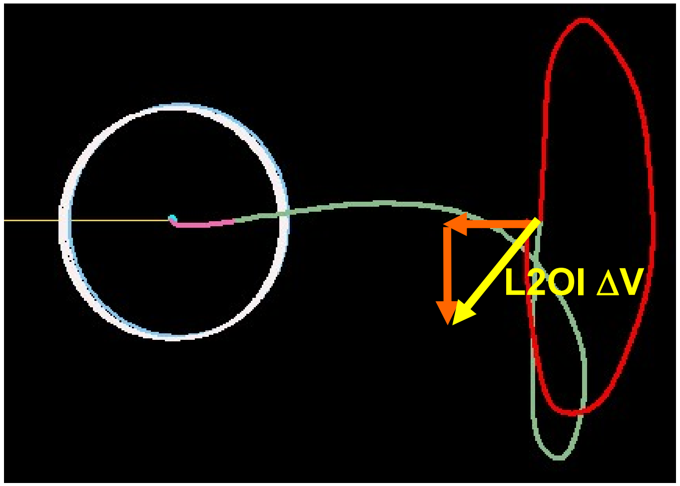
- Detailed orbit work for Constellation-X not yet performed
  - JWST's data shows that the min. size of a "zero insertion delta-v" L2 orbit is a function of the launch date
  - Several JWST launch dates for 800,000 km orbit; none for 7000,000 km orbit
- If too few "zero insertion delta-v" 700,000 km launch dates found for Con-X, then at L2 Orbit Insertion execute Y-amplitude reduction maneuver
  - Y-amplitude reduction maneuver is the present baseline; delta-v ≈ 25 m/s (required propellant is carried in mass rack-up)
  - Further study could reduce this delta-v number

JWST Launch Opportunities into Orbits of Various Amplitudes





Con-X Y-Amplitude Reduction Maneuver



Mission Timeline

- Launch (L): T-0
  - Instruments and Cryo completely deenergized, S/C mostly unpowered
  - LV First stage is ballistic (falls into ocean)
- Transfer Trajectory Insertion (TTI): L + 25 to 120 minutes
  - Need live RF Comm w/ ground (have TDRSS capability)
- LV Separation: TTI + 5 minutes
  - LV 2nd stage remains on trajectory behind ConX to near-L2 cruise
  - Turn S/C on; acquire Sun-positive nominal attitude; deploy S/A, HGA
  - Begin S/C Checkout; Some portions of Payload on, Cryo off
- ELV Dispersion Corrections: TTI + 12 to 24 hours
- First and Second Mid-Course Correction: TTI + 15, TTI + 60 days
- L2 Orbit Insertion (L2OI) / Y-Amplitude Lowering Maneuver: ~ TTI + 100 days
- Cryo on, Cool Down
- Jettison / Open Telescope Covers
- Calibration w/ Celestial Targets
- Science Ops
  - L2 Stationkeeping burns: Every 21 - 90 days (no less than 3 weeks for undisturbed ranging)
  - L2 Momentum Unloading Burns: Every 2-3 days during slews
- EOM Disposal: L + 10 years +++ …
  - Delta-V < 1 m/s to driftaway trajectory, then passivate Observatory

Observation and Pointing

- Field of Regard
  - Pitch: +/- 20° off Sunline
  - Yaw: +/- 180°
  - Roll: +/- 20° off Sunline
- Pointing Control (3σ)
  - Pitch: 10 arcsec
  - Yaw: 10 arcsec
  - Roll: 30 arcsec
- Star Tracker Attitude Knowledge (3σ)
  - Pitch: 3 arcsec
  - Yaw: 3 arcsec
  - Roll: 30 arcsec
- Observation duration
  - Minimum 30 minutes
  - Average 10 hours
  - Maximum 48 hours
- Slew
  - Average slew magnitude: 60 degrees, completed in 1 hour
  - Average # of slews per day: 2.5 during first year of Mission, less later
- Momentum Build-up due to Center of Pressure / Center of Mass (CP/CM) Offset
  - Momentum unload w/ two 22-N thrusters in forceless pure torque couple w ~10m arm
  - Momentum management propellant required for 10 years (w/ assumed 1m CP / CM offset) corresponds to ~ 2 m/s equivalent delta-v
  - Momentum dumps during slews (take a few minutes) won't interfere w/ observations
- Operational Efficiency
  - ~85%, when averaged over the mission life
- Timing accuracy
  - Photon arrival tagged to UTC to ±100 μsec

Propellant Calculations

DELTA V BUDGET				
	Estimate	ACS Tax	Margin	Subtotal
Launch Window	10 m/sec	5%	0%	11 m/sec
ELV Dispersion Correction	40 m/sec	5%	0%	42 m/sec
Mid-Course Correction	10 m/sec	5%	10%	12 m/sec
Halo Adjustment	25 m/sec	5%	10%	29 m/sec
L2 Stationkeeping for 10 years	40 m/sec	5%	10%	46 m/sec
Momentum Management	2 m/sec	5%	10%	2 m/sec
De-orbit	1 m/sec	5%	10%	1 m/sec
Total Equivalent Delta V				**143 m/sec**

CBE PROPELLANT BUDGET		
	CBE	*Prop Calculation against CBE of 4685 kg*
CBE Dry Mass	4685.1 kg	
Prop Mass (use equivalent Isp =275)	253.8 kg	
5% Ullage and Residual	13 kg	
CBE Propellant Mass	**266.5 kg**	

ALLOCATION PROPELLANT BUDGET		
	Allocation	*Prop Calculation against Alloc of 6091 kg*
Alloocation Dry Mass	6090.6 kg	
Prop Mass (use equivalent Isp =275)	330.0 kg	
5% Ullage and Residual	16 kg	
Allocated Propellant Mass	**346.5 kg**	

Mass Rackup

Payload			
	Estimate (kg)	Contingency	Allocation (kg)
SXT	2282.2 kg	30%	2966.9
Misc Payload Items	35.6	30%	46.3
SEP	200.0	30%	260.0
Payload Total	**2517.8 kg**	**30%**	**3273.2 kg**

Bus			
	Estimate (kg)	Contingency	Allocation (kg)
Avionics	100.0	30%	130.0
Attitude Control	68.0	30%	88.4
Communications	30.0	30%	39.0
Mechanisms	146.6	30%	190.6
Structure	1131.6	30%	1471.1
Power	104.0	30%	135.2
Propulsion	48.0	30%	62.4
Thermal	186.3	30%	242.1
Harness	188.0	30%	244.4
Bus Total	**2002.4 kg**	**30%**	**2603.2 kg**

Observatory			
	Estimate (kg)	Contingency	Allocation (kg)
Science Payload Total	2517.8	30%	3273.2
Bus Total	2002.4	30%	2603.2
Separation System	164.8	30%	214.3
Vehicle Dry Mass	**4685.1 kg**	**30%**	**6090.6 kg**
Propellant Mass	266.5		346.5
Observatory Wet Mass	**4951.6 kg**	**30%**	**6437.1 kg**

Atlas V 551 Launch Vehicle			
	Wet Mass Est. (kg)	Contingency	Wet Mass Alloc. (kg)
Throw Mass: 6305 kg	4951.6 kg (79% of Throw Mass)	30%	6437.1 kg (102% of Throw Mass)
		27%	6305.0 kg (100% of Throw Mass)

Power Loads

Payload															
	Science Mode w Comm [W]			Stationkeeping manuevering [W]			Launch [W]			Cruise [W]			Safehold [W]		
	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated
XMS	1616.0	30%	2100.8	1280.4	30%	1664.5	0.0	30%	0.0	1616.0	30%	2100.8	1280.4	30%	1664.5
FMA Thermal	877.0	30%	1140.1	877.0	30%	1140.1	0.0	30%	0.0	877.0	30%	1140.1	877.0	30%	1140.1
SEP	85.0	30%	110.5	0.0	30%	0.0	0.0	30%	0.0	85.0	30%	110.5	0.0	30%	0.0
Payload Total	**2578.0**	**30%**	**3351.4**	**2157.4**	**30%**	**2804.6**	**0.0**	30%	**0.0**	**2493.0**	**34%**	**3351.4**	**2157.4**	**30%**	**2804.6**

Bus															
	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated
Mechanical	17.0	30%	22.1	17.0	30%	22.1	5.0	30%	6.5	17.0	30%	22.1	5.0	30%	6.5
ACS	75.0	30%	97.5	469.0	30%	609.7	0.0	30%	0.0	66.0	30%	85.8	57.0	30%	74.1
Thermal	100.0	30%	130.0	100.0	30%	130.0	0.0	30%	0.0	100.0	30%	130.0	232.0	30%	301.6
Propulsion	29.2	30%	38.0	5.0	30%	6.5	5.0	30%	6.5	5.0	30%	6.5	5.0	30%	6.5
C&DH	119.0	30%	154.7	119.0	30%	154.7	22.0	30%	28.6	66.0	30%	85.8	74.0	30%	96.2
RF Comm	110.0	30%	143.0	44.0	30%	57.2	0.0	30%	0.0	44.0	30%	57.2	44.0	30%	57.2
PSE	192.0	30%	249.6	184.6	30%	240.0	1.8	30%	2.3	182.4	30%	237.1	165.9	30%	215.7
Harness Loss	7.5	30%	9.8	7.3	30%	9.5	0.1	30%	0.1	7.2	30%	9.4	6.6	30%	8.6
Bus Total	**649.7**	**30%**	**844.6**	**945.9**	**30%**	**1229.7**	**33.9**	**30%**	**44.1**	**487.6**	**30%**	**633.9**	**589.5**	**30%**	**766.4**

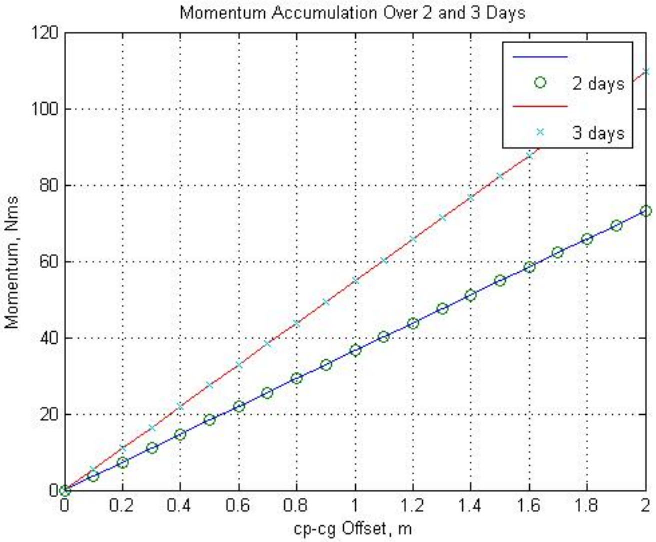
Observatory															
	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated	Estimate	Cont.	Allocated
Obs. Total (W)	**3227.7**	**30%**	**4196.0**	**3103.3**	**30%**	**4034.3**	**33.9**	**30%**	**44.1**	**2980.6**	**34%**	**3985.3**	**2746.9**	**30%**	**3571.0**

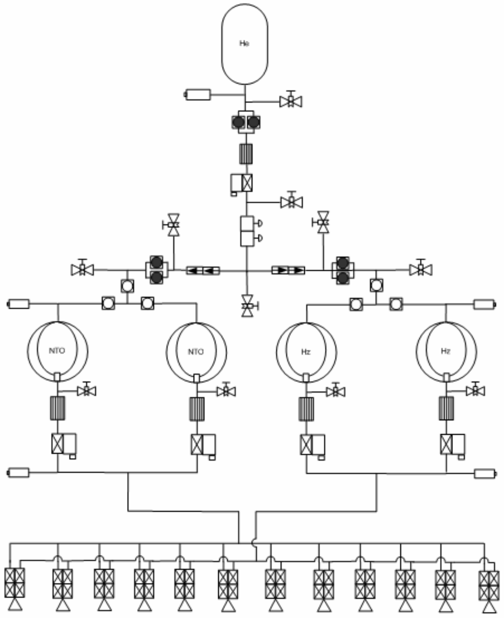
SEP Abs. Max. Mass Impact

Subsystem	Modification	Rationale	Mass (kg)
Avionics	Add card Potential H/W modifications (I/F, mechanisms- unknown mass, $$)	Accommodate SEP	3.0
Attitude Control	None	Margins will accommodate mass increase	0.0
Communications	No hardware changes; increase xmit link from 10 Mbps to 14 Mbps	Reduction in link margin to 3 dB; was higher	0.0
Mechanical	Add SEP secondary structure Add SEP S/A Panel Area Adjust counter weights	Accommodate SEP	43.0
Power	Increased Solar Array Size Re-scale PSE	Increased Power Demand	4.0
Propulsion	None	Sized for LV performance	0.0
Thermal	Increased MLI 10 Thermistors 4 Thermostats	Accommodate mechanical changes	3.1
Harness	Increase harness for signal/power	Accommodate SEP I/F's	3.0
DSN; Ground Network	Increased contact time	Data volume increase	N/A
Mission Ops	Increased contact time; increased storage	Data volume increase	N/A
Flight Software	I/F mgmt I/F development Testing	Second payload requires	N/A
Payload	Add'l Payload	SEP Addition	200.0
		CBE Total	**256.1**
		Contingency 30%	76.8
		Propellant Lien	18.9
		GRAND TOTAL SEP MASS IMPACT	**351.8**

Subsystems At A Glance

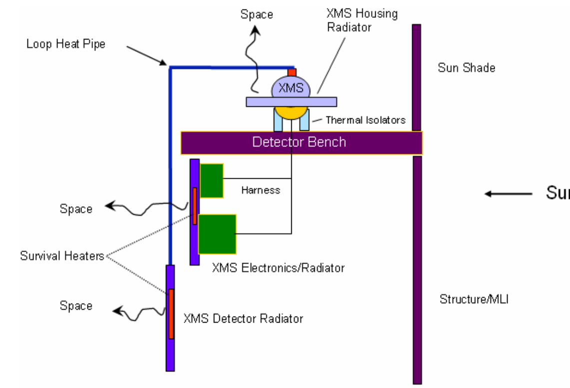
- **Mechanisms**
  - **Deployables: Separation System, Jettisoned SXT Outer Covers, SXT Inner Covers, S/As, HGA, Fore Sunshield, Cryostat covers**
  - **Focus Mechanisms (w/ flex Loop Heat-pipes), XMS Filter Wheels**
- **GN&C**
  - **Traditional GN&C system, all COTS components**
  - **3 Star Trackers (one as cold spare)**
  - **Four reaction wheels arranged in a [4:4:1] pyramid**
  - **Manageable (30 cm) CM/CP offset, 2 m/s equivalent propellant for 10 years, 2-3 days between offloads**
- **Propulsion**
  - **Pressure Regulated NTO/Hz biprop system**
  - **Twelve 22N Biprop Thrusters**
  - **Thrusters arranged in forceless pure couples w/ < 0.5 mm/s per day residual delta-v from momentum unloads**
  - **All requirements met even w/ one thruster failure**

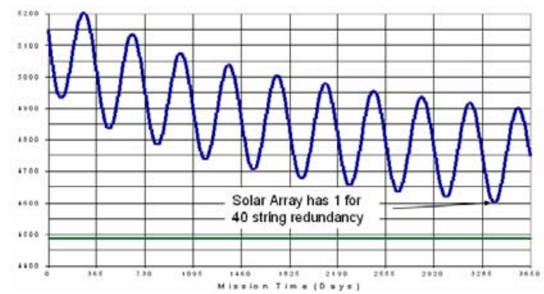


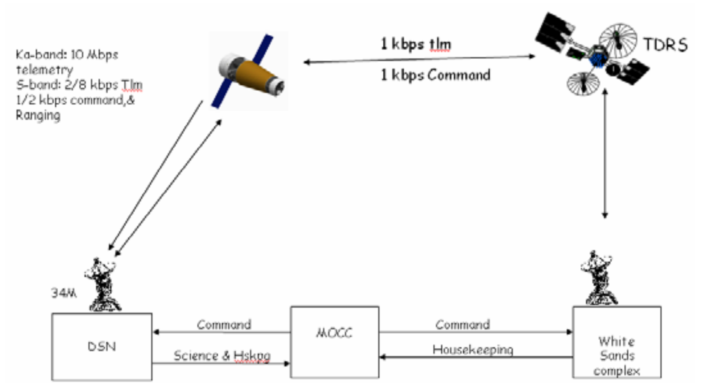


Subsystems At A Glance

- **Thermal**
  - Traditional passive thermal control for Spacecraft
  - S/C radiator area is 3.4 m2 to dissipate 716 W component power
  - Loop Heat Pipes w/ dedicated radiators for XMS
- **Electrical Power**
  - 120 VDC Bus
  - 20 m2 S/A
  - Small battery sized for Launch only (have Sun-positive Safe Mode)
- **RF Comm**
  - 0.5 meter S/C antenna, 10 W RF xmit power, TWTA
  - Ka-Band for science and data dumps via DSN 34 meter
    - Data dumps at 14 Mbps, 34 minute contact, 10 watts RF (use TWTAs)
  - S-Band TT&C via HGA to DSN 34 meter
    - 2 kbps command, 8 kbps telemetry
  - S-Band TT&C via omni to DSN 34 meter
    - 1 kbps command, 2 kbps telemetry
  - S-Band thru TDRSS for launch and LEO critical events
    - 1 kbps command, 1 kbps telemetry
  - 30 min / day ranging for orbit determination

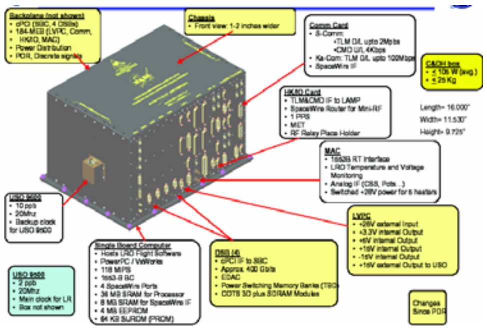


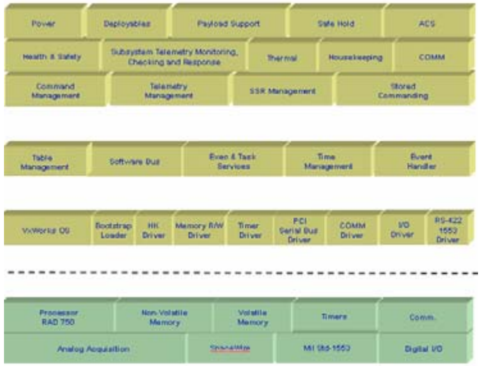


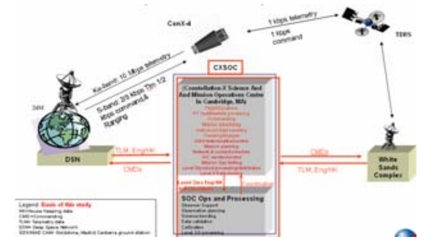


Subsystems At A Glance

- **C&DH**
  - Avionics boxes all redundant, all cross-strapped
  - BAE RAD 750 SBC
    - Power PC 750 microprocessor, 240 MIPS @ 132 MHz
  - 2 days storage
    - 170.3 Gbit (21.3 Gbyte) SDRAM board
  - SpaceWire interfaces
- **Flight Software**
  - Reuse LRO C&DH FSW
  - New development for all mission specific components: ACS, Instrument support, mission-specific ops concept support, power electronics, etc.
- **Mission Ops**
  - Reuse existing MOC; all GOTS/COTS-based
  - Relatively simple ops concept allows automation for unstaffed operations, 8x7 profile for routine ops
  - Data Latency: 72 hour required, 24 hour desired (on the ground)

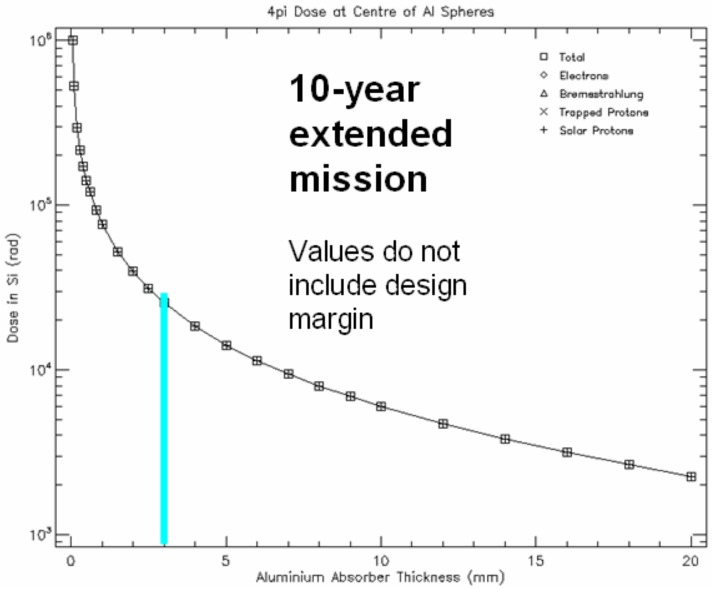


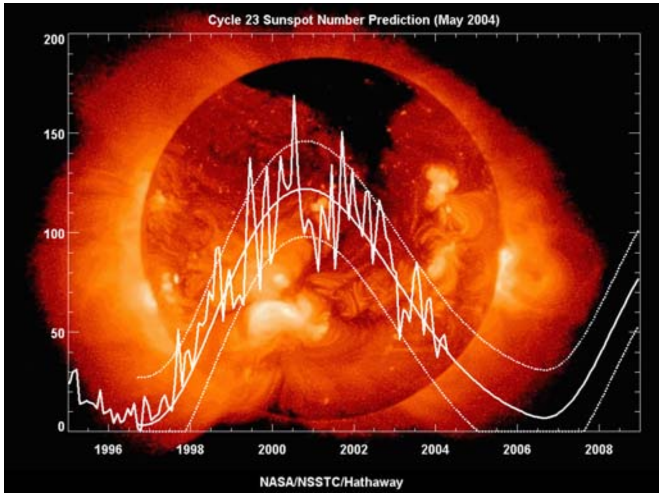




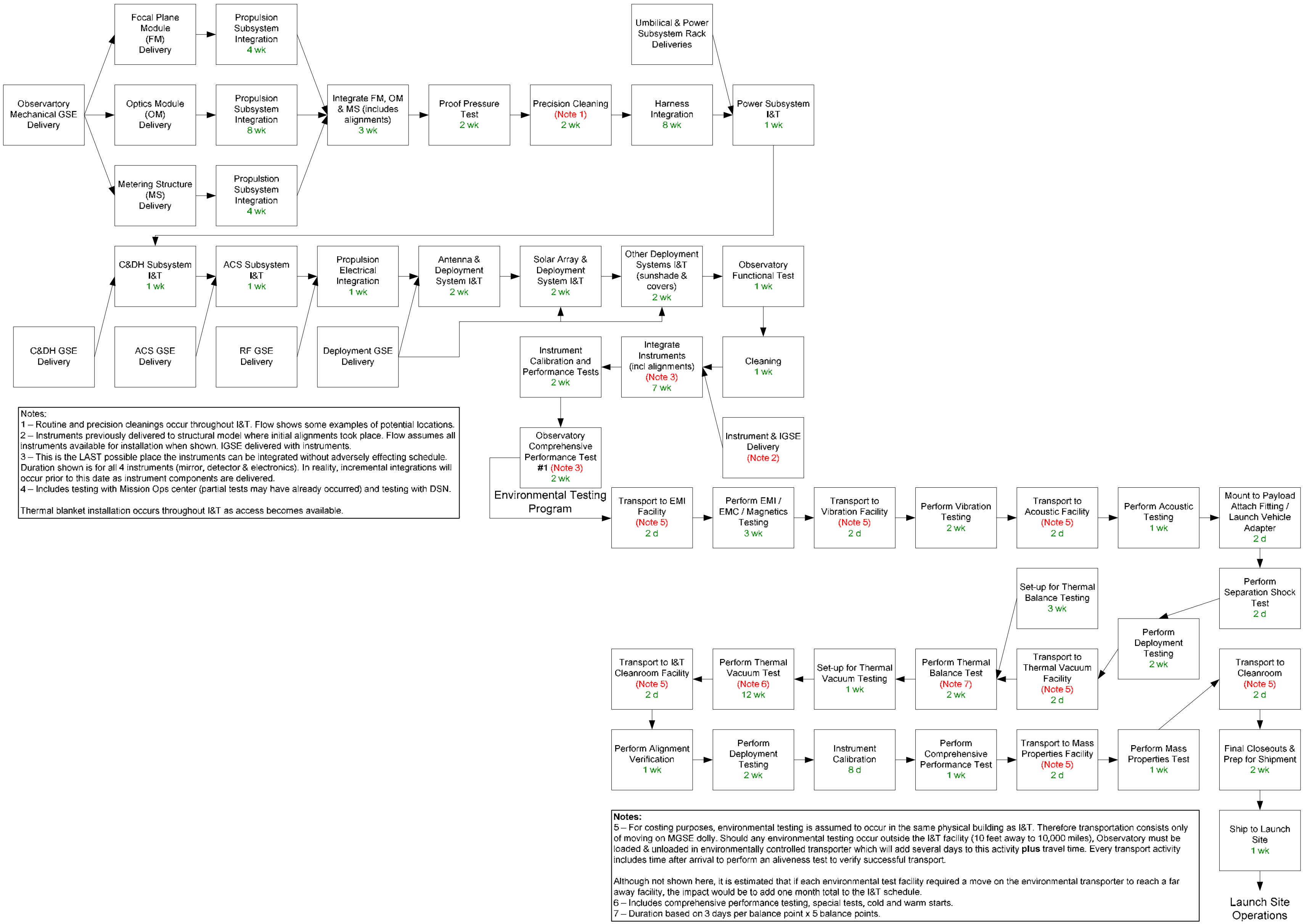
Subsystems At A Glance

- Radiation
  - Severe for Single Events Effects
  - TID ~ 21 kRads @ 1.5 mm Al
  - 42 kRad parts recommended
- Cleanliness
  - Contamination is a serious concern for Mirrors, Detectors, and Thermal Control Surfaces
  - Tight Observatory requirements and implementation plan
    - FMA purge during Observatory ground ops
    - Contamination Control Program (factored in present I&T plans)
- Reliability
  - Class-B Mission





Integration and Test Flow



Path Forward

- Scrub mass to increase margins. Potential areas:
  - Optimize structure mass, complete FEM
  - Orbit Analysis to optimize method to achieve final orbit
  - Commit to solar torque balancing observing strategy
- Optimize payload mass
- Evaluate accommodation of various SEP concepts

BACKUP MATERIAL
-
MISSION CONFIGURATION DETAILS

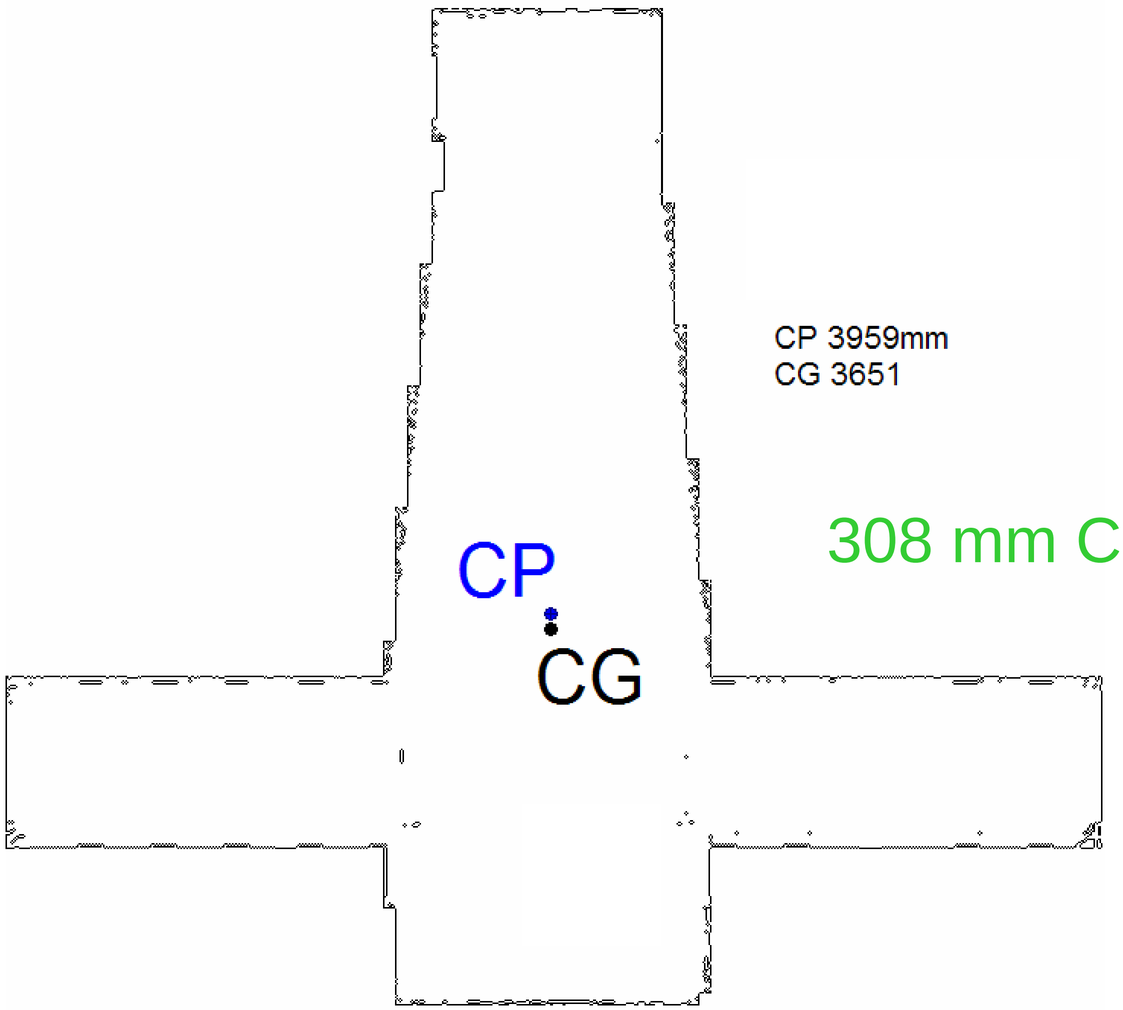
GN&C Driving Requirements

- Pointing knowledge requirements drive star tracker selection, orientation
  - 3 arcsec pitch/yaw, 30 arcsec roll, 3-sigma
  - Pointing knowledge requirements are at the limit of COTS star tracker-gyro sensors.
  - Two active star trackers used (3 total, one cold spare) to assure margin on requirements
- Tracking requirement drives thruster placement, operation
  - Three-week tracking arcs with < 0.5mm/s per day residual delta-V
- Momentum storage and slew requirements drive reaction wheel size, orientation
  - 2-3 days between unloads
  - 60-deg slew in 60 minutes
- Instrument sensitivity to Sun drives fail-operational sun-pointing safehold
  - Sun pointing attitude must be maintained even during transition to safehold
  - Also minimizes battery requirements

GN&C Overview

- Three-axis stabilized, inertial pointing
  - X axis points to Sun
  - Z axis points to science target
- Four reaction wheels arranged in [4:4:1] pyramid
  - Slews require authority in X axis
  - Momentum accumulation primarily in Y axis
- Star trackers, gyro mounted on common optical bench
  - Two active star trackers, canted wrt instrument boresight
    - Provides roll measurement accuracy
    - Also provides increased pointing accuracy by averaging
  - Instrument mirror-to-detector structural motion assumed tracked by fiducial lasers and quad cells
- Momentum unload at 3 day intervals using thrusters
  - Thrusters placed for maximum moment arm
    - Minimizes residual delta-V
    - Maximizes fuel efficiency
- Sun pointing attitude maintained for all modes: Science, Slew, Maneuver, Safehold, and Cruise

CM/CP Offset Estimate



CP 3959mm
CG 3651

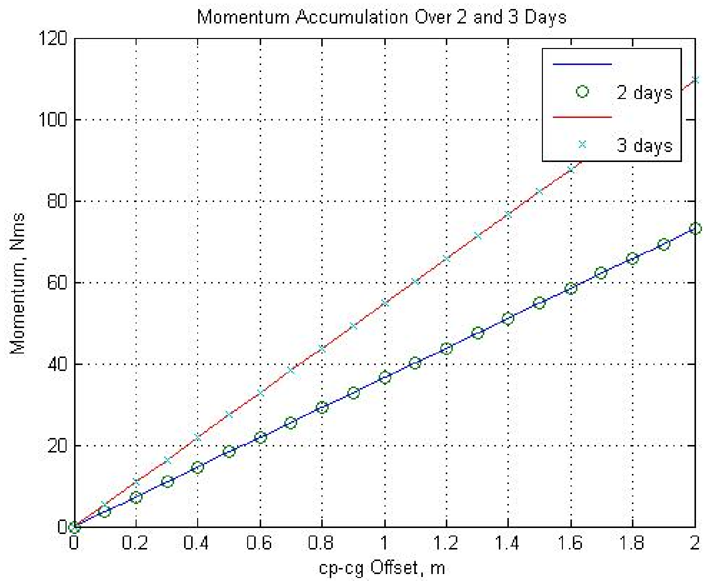
308 mm CP/CG offset

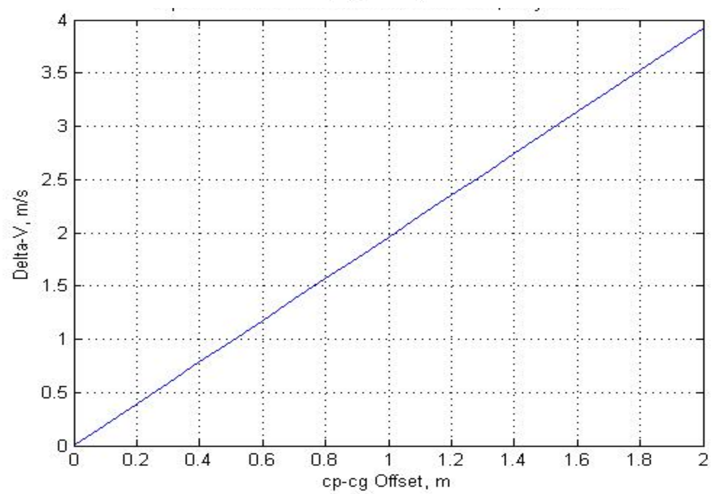
Momentum Management

Assuming worst case of 2-m cp-cg offset, and 3 days between unloads, the wheels must accommodate 120 Nms in the Y axis

- Systems used 1 m offset for equivalent delta-v budget allocation

- Momentum unload uses two 22-N thrusters separated by 10 m, nominally forming a pure couple
  - Thrusters fired for 0.55 sec every 3 days, preceding or during a slew between targets
  - Thrusters fired in short pulses, spaced about 10 sec to allow reaction wheels to catch up
  - Thrusters matched to < 5%, causing 0.01 mm/sec per day residual delta-V
- Momentum accumulation rate may be reduced by observation strategy
  - Balance targets symmetrically around the Sun line over a 2-3 day period





Reaction Wheel Sizing

- Momentum capacity
  - 120 Nms momentum accumulated on Y axis in 3 days
- Slew capability
  - Requirement is 60 deg in 60 minutes
  - Allowing 10 minutes for settling, a rate-limited slew requires 74 Nms momentum storage in the X axis
- Requirements met by 4 Honeywell HR14(75) reaction wheels in a pyramid
  - Reaction wheel momentum: 75 Nms
  - Reaction wheel torque: 0.2 Nm
  - Mass: 10.2 kg per wheel
    - To save 2.3 kg per wheel, wheel momentum is only 27 Nms
- Notional pyramid gives [4:4:1] x,y,z capacity
  - Momentum capacity:
    - [208 208 52] Nms with four wheels
    - [156 156 39] Nms with three wheels
  - Torque capacity:
    - [0.56 0.56 0.14] Nm with four wheels
    - [0.42 0.42 0.10] Nm with three wheels
- Spare capacity accommodates uncertainties in momentum unloading design, thruster placement, mass properties, and slew rate optimization

GN&C Hardware Components

Component Name	Vendor	Model	Qty	Mass [kg]	Mass Subtotal [kg]	Cost [k$]	Cost Subtotal [k$]	Delivery Time A.R.O.*	Power[W]	
									Orbit Avg.	Power
Reaction Wheels	Honeywell	HR14 (75)	4	10.6	42.4	170	680	12	32	420
Gyros	Litton	SIRU	1	5.44	5.44	1000	1000	12	22	40
Coarse Sun Sensors	Adcole	Coarse Sun Sensor	6	0.16	0.96	48	288	6	0	0
Fine Sun Sensors	Adcole	Model 20910 Two Axis Fine Digital	2	1.361	2.722	200	400	12	2.8	2.8
Star Trackers	Ball Aerospac	CT-602	3	5.409	16.227	650	1950	18	18	18
					67.749		**4318**		**74.8**	**480.8**

* After Receipt of Order

S/C Thermal Requirements

- Spacecraft Component Temperature Limits:
  - The thermal control system shall maintain all operating components within their operational limits.
  - The thermal control system shall maintain all non-operating components within their survival limits.
  - Electronic Components Limits
    - Operating Temperatures -10°C to 40°C
    - Survival Temperatures -20°C to 50°C
  - Li-Ion Battery for Spacecraft
    - Maintain operating temperatures of 0°C to 30°C
    - Nusil Interface material for battery mount interface
  - Solar Array Temperatures
    - Operating limits of -120°C to 100°C

Component	Survival Heater Power (Watts)
XMS Cold Head Radiator (4)	556 total
Option 1: XMS Electronics – SQUID MUX, SPE, LVPS, ADR Control, Cyrocooler Control	800 (200 Per XMS)
Option 2: XMS Electronics– SQUID MUX, SPE, LVPS, ADR Control, Cyrocooler Control, w/SEP	846 (200 Per XMS + SEP 46 Watts)
FMA (4)	1140 (285 each)

Spacecraft Components	S/C Heater Power Estimates (Watts)
Battery	20.0
Solar Array Drive Motors (2)	30.0 (15 each)
HGAS Gimbal (1)	15.0
ST #1	10.0
ST #2	10.0
Propulsion System	147.0 Watts
Estimated S/C Survival Heater Power Total	~ 232.0 Watts

- Bi-Prop Propulsion System – 4 tanks, Hz tank and NTO tank.

- Duty cycle design for all components is 70%
- Valve heaters are sized at 50% duty cycle
- Redundant heater circuits are used for all propulsion components
- Operational Limits:
  - Fuel lines +10 to +40°C
  - Thruster valves +10 to +40°C
  - Hz Tank +10 to +40°C
  - PCM +10 to +40°C
  - F&D +10 to +40°C
  - NTO Tank - 10 to +40°C

Loop Heat Pipe Heaters	Estimated Power (Watts)
Loop Heat Pipe Survival Heater (4)	120.0 total (30.0 each)
Start-up/Shutdown Heater Power (4)	200.0 total (50.0 each)
Loop Heat Pipe Controller (4)	120.0 total (30.0 each)

Orbital Average Heater Power Requirement Watts (based on SDO)	
Exterior Lines	22.0
Interior Lines	3.2
Tanks (6)	78.0
PCM (Pressure transducer)	3.4
F&D	1.2
Thruster Valves (5 lb thrusters)	39.24 (3.27 Watts per thruster valve x 12 = 39.24 Watts)
Estimated Heater Power Total	147.0 Watts

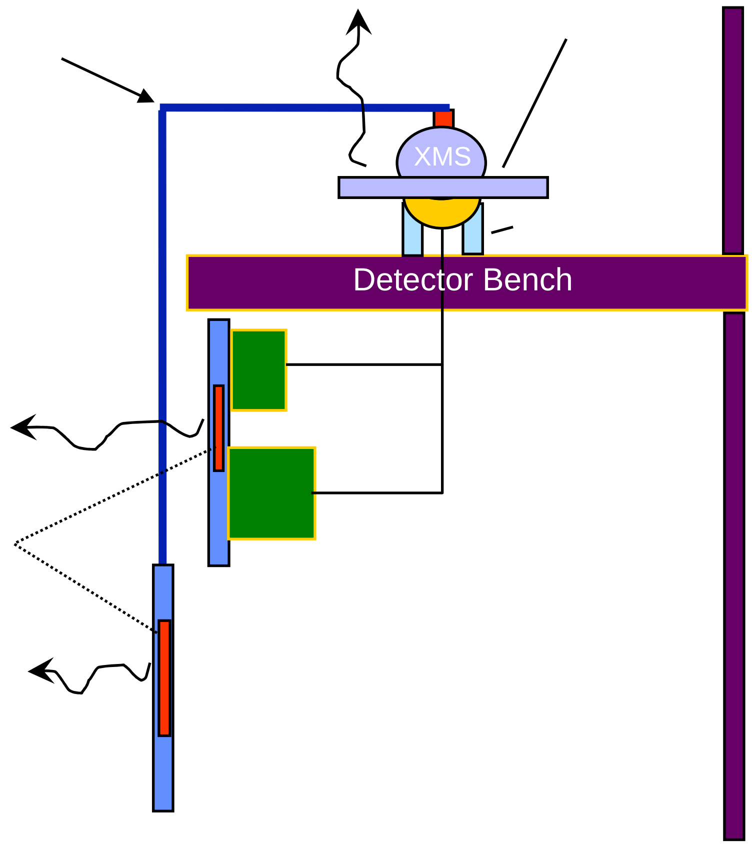
S/C Thermal Design Concept

- Passive Thermal Control Design System for Spacecraft
- S/C Radiators (NS43G White Paint Radiators for spacecraft components radiators)
- Back side of Solar Array Panels Painted with NS43G White Paint.
- Internal Surface Coatings of bus – high emittance surfaces (Aeroglaze Z306 Black Paint) except for Battery (may need an internal closeout MLI to isolate the battery).
- External MLI layer insulated on spacecraft bus
  - Outer layer Germanium Black Kapton MLI, conductive.
  - 15 layers MLI make-up
- Kapton film heaters mounted to box to panel interfaces
- Flight thermistors for telemetry of temperatures
- Cho-Seal interface material used for box to panel interface (electrically and thermally conductive) except for Battery (Nusil interface).
- Redundancy in thermal system – prime and redundant heaters, thermostats and thermistors – single fault tolerance built in TCS.

S/C Radiator and Heater Sizing

- S/C Radiators are sized in worst hot operating case
- S/C Radiator area required is approximately 3.4 m^2 to dissipate an assumed 716.0 Watts of spacecraft component power.
- Operating and Survival mode heater power is sized in worst cold operating case.
- GSFC Gold Rules call for a maximum of 70% heater duty cycle for an active heater control thermal design
  - In sizing heater electrical resistance (R), orbital average heater power shall be no more than 70% of peak heater power (V**2/R)

XMS Thermal Block Diagram (4x)



Thermal Components

- Prime and redundant external and internal thermistors mounted per critical component at interface.
- Type YSI 44910 thermistors
  - Prime and redundant flight thermistors; meet GSFC specification S-311-P-18
- Platinum Resistance Thermometers (PRTs) mounted on solar array panels (Type: Goodrich 0118MF2000A)
- Tayco Kapton film heaters
  - All heater circuits are prime and redundant (SDO has dual element heaters – can save on real estate – prime and redundant in one heater element)
  - Heaters can be mounted directly to box or to the box to panel interface
  - Thermostatically controlled heater circuits, each with series redundant thermostats Honeywell 701 series (GSFC specification S-311-641)
- ChoSeal interface material (sheet material)– thermally and electrically conductive – box baseplate to panel interface. Nusil used for battery interface.

Thermal Mass Budget

No.	Subsystem Component Name	Qty	Mass[kg]	Mass Subtotal[kg]
1	Component Set A:			
2	MLI	1	54	54
3	Thermofoil Heaters - prop system, s/c elec	184	0.05	9.2
4	general coatings - tapes	16	0.25	4
5	Component Set B:			
6	Thermistor, standard	210	0.025	5.25
7	Thermostats	184	0.025	4.6
8	Misc Flight Thermal H/W - closeout vents	10	2	20
9	Collimator Payload Kapton film heater system	4	14.4	57.6
10	Loop Heat Pipe- mirror assembly	4	4.5	18
11	Heat Pipe Radiator Panel	1	13.6	13.6
			Total:	**186.25**

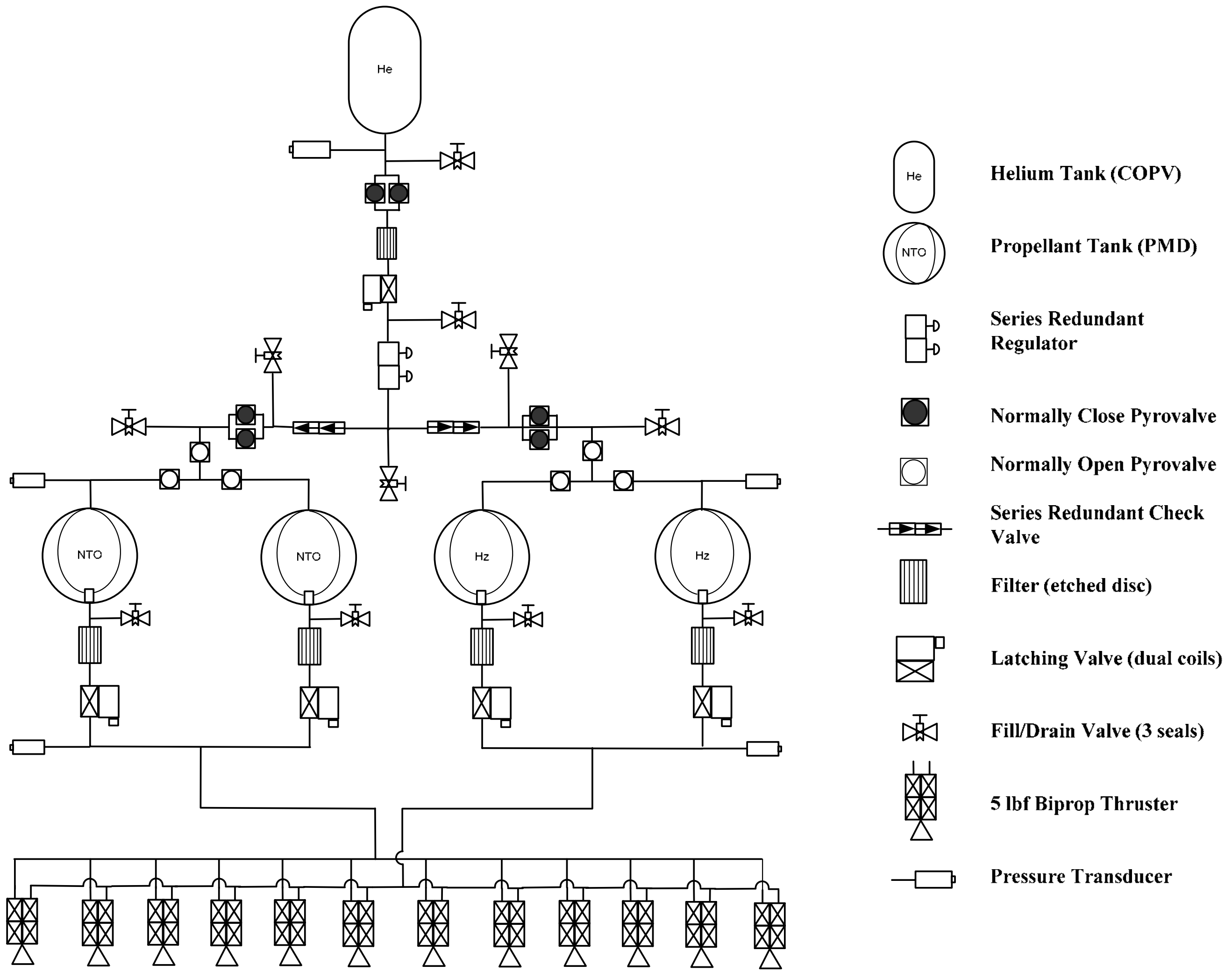
Propulsion Subsystem Configuration

- Pressure Regulated, NTO/Hz, Bipropellant Propulsion Subsystem
- Series Redundant He Regulator With High Pressure Isolation Latch Valve For Long Life Operation
  - SDO regulator
  - Supplier = Mu
  - HP latch valve/regulator combination is dual fault tolerant against leakage
  - Operational pressure range = 5000 - 360 psia
  - Regulated pressure range = 320 - 240 psia
- Twelve (12), Single String, 22N Biprop ACS And Station Keeping Thrusters
  - SDO/Navy/Loral thrusters
  - Baseline supplier is AMPAC (Japan possible alternate)
  - Pt combustion chamber (No life-limiting coating)
  - Mass mixture ratio (NTO/Hz) =0.65 to 1.2 (0.86 nominal)
  - Isp = 310 sec @ MR=0.86 and a feed pressure = 300 psia

Propulsion Subsystem Configuration

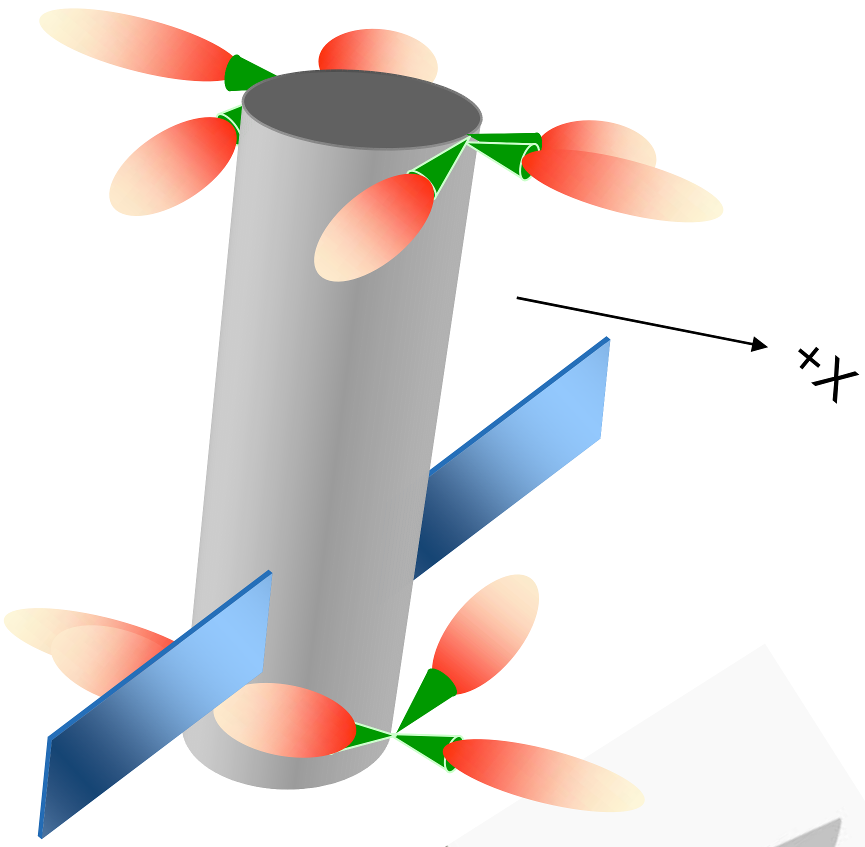
- One (1) COPV Titanium He Tank
  - Supplier = ATK (PSI inc.)
  - Volume = 3,052
  - MEOP = 2,176 psia
  - ETS8 Xe Tank
- Monolithic Titanium NTO And Hz Tanks (2 each)
  - Supplier = ATK (PSI inc.)
  - Surface tension propellant management device (PMD)
  - Hz tank volume = 5,580 in^3 (INMARSAT Tank)
  - NTO tank volume = 3,575 in^3 (Mars Observer Tank)
  - MEOP = 400 psia
  - Tanks are spherical to allow installation with the PMD outlets aligned opposite to S/C Δv vector (no burn limitation)
- Propellant Manifolds And Components Are All Titanium
  - Titanium/Stainless Steel bimetallic joints used to transition to from Ti manifold to SS steel thruster propellant control valves
  - Prevents Fe nitrates and flow decay

Propulsion Subsystem Block Diagram



Thruster Placement

- Twelve 22-N thrusters in 4 clusters
  - One thruster in each cluster points in +/-X direction
  - Two thrusters canted to achieve 6-DOF, and avoid contamination
  - Thruster orientations will need optimization for L2 insertion maneuver
  - Plume impingements considered
- Two clusters near each end of S/C, to maximize moment arm
  - Important for minimization of residual delta-V
  - May be reduced modestly to reduce instrument contamination
- Redundancy
  - Thruster Configuration Allows For A Loss Of A Single Thruster With No Impact On A 5 Year Mission Life



Propulsion Subsystem Budgets

ConX-4 Mass, Power and Cost Budgets

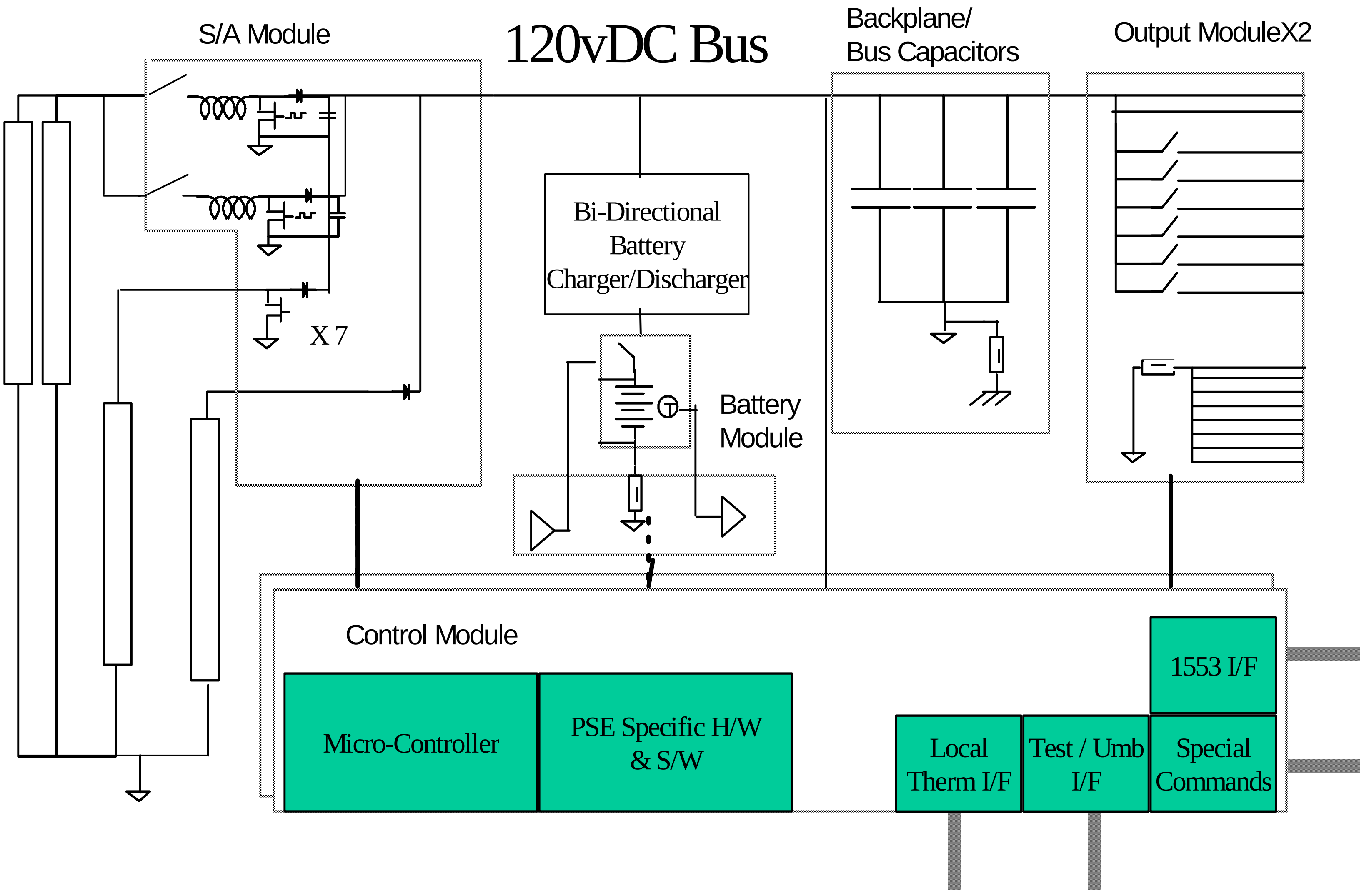
Component	Supplier	Part No.	Number	Unit Mass (kg)	Unit Power[1] (watts)	Unit Cost ($K)	Total Mass (kg)	Total Power[1,2] (watts)	Total Cost ($K)
Hz Tank 5,580 in^3	PSI	80364-1	2	5.67	NA	300	11.34	NA	600
NTO Tank 3,575 in^3	PSI	80353-1	2	3.86	NA	300	7.71	NA	600
He Tank 3,052 in^3	PSI	80412-1	1	6.99	NA	100	6.99	NA	100
22N Hz/NTO Thruster	AMPAC	A0893020	12	0.74	0	90	8.87	0	1080
Hz Valve (series redundant)	AMPAC	Indentured Part	24	NA	35.6	NA	NA	854.4	NA
NTO Valve (series redundant)	AMPAC	Indentured Part	24	NA	35.6	NA	NA	854.4	NA
Hz Valve Heaters (primary/redundant)	AMPAC	Indentured Part	24	NA	2.6	NA	NA	63.36	NA
NTO Valve Heaters (primary/redundant)	AMPAC	Indentured Part	24	NA	2.6	NA	NA	63.36	NA
Injector Heaters (primary/reduncant)	AMPAC	Indentured Part	24	NA	4.3	NA	NA	102.24	NA
3/8", dual coil, LP Latch Valve	Vacco	V1E10362-01	4	0.73	NA	30	2.90	NA	120
3/8", dual coil, HP Latch Valve	Vacco	V1E10560-01	1	0.73	NA	30	0.73	NA	30
Pyro Valves (NO/NC)	Conax	TBD	12	0.16	NA	15	1.91	NA	180
Check Valve (dual seat)	Vacco	V0E10495-01	2	0.11	NA	25	0.23	NA	50
He Regulator (Series Redundant)	Mu	Inlet 5000 to 360 psig	1	1.25	NA	100	1.25	NA	100
HP Filters (10μ)	Vacco	F1D10286-01	1	0.11	NA	10	0.11	NA	10
LP Filters (15μ)	Vacco	F1D10559-01	4	0.30	NA	10	1.20	NA	40
Fill/Drain Valves	Vacco	TBD	11	0.11	NA	10	1.25	NA	110
Pressure Transducer	Paine	TBD	5	0.27	1	15	1.36	5	75
Manifold+ etc.	TBD	TBD	1	2.27	NA	100	2.27	NA	100
						Total =	48.1	See Note 2	3,195

[1] Power at 28 Vdc

[2] Valve heaters are continuously powered on, thermostatically controlled, and sized for a 50% duty cycle; when thruster is firing, valve heaters will turn off. Catbed heaters are powered on 2 hours prior to each maneuvers then turned off during the maneuver for thrusters firing steady state.
Thruster valves are powered on only when a thruster is fired.

- **Subsystem Dry Mass = 48.1 kg**
- **Cost = $3.2M**
- **Power = 5 watts For Pressure Transducers**
  - **Thruster power is booked by Avionics**
  - **Thermal control of tanks, lines, thrusters is booked by Thermal**

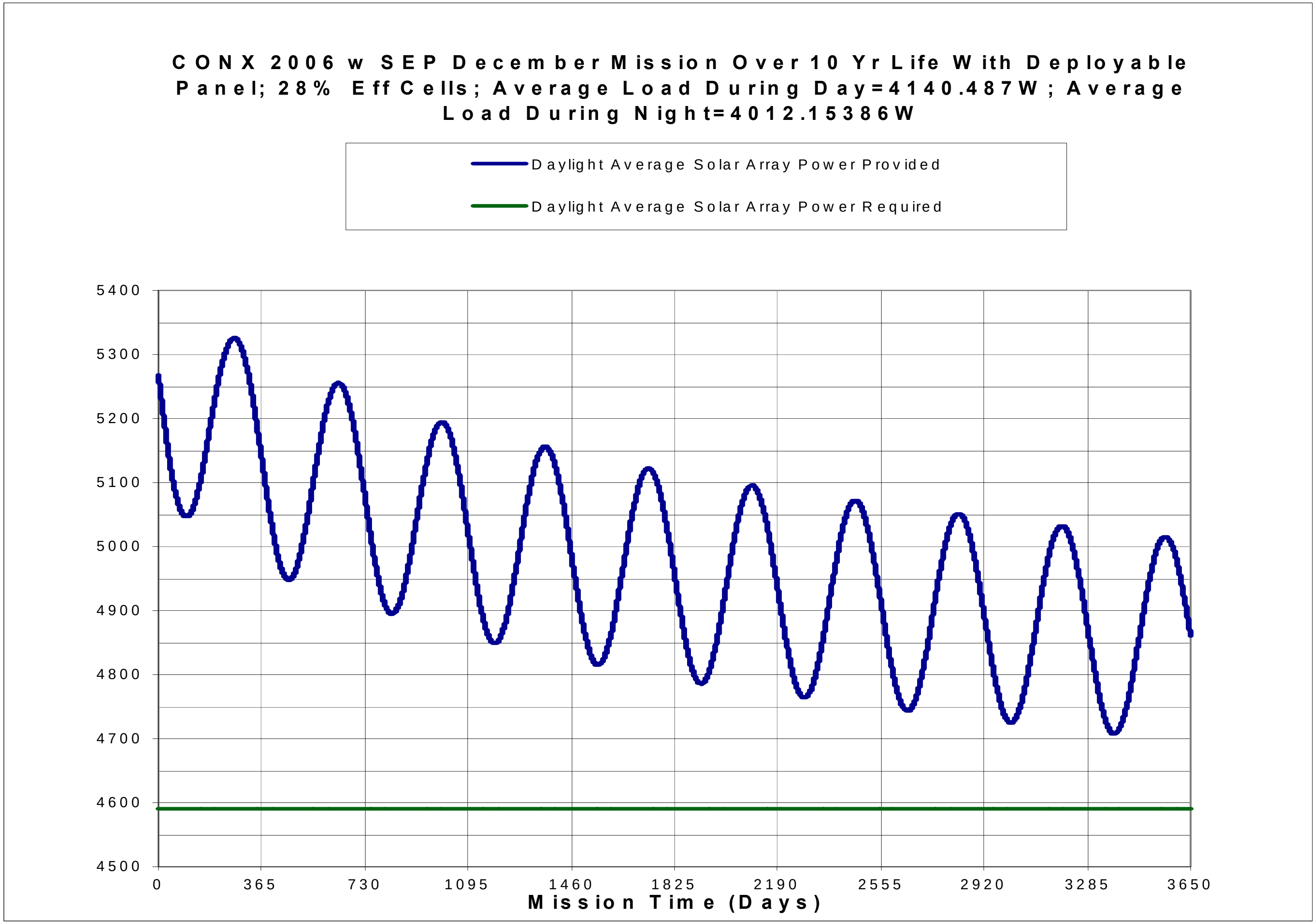
EPS Block Diagram



Power Loads

CONX 2006 w SEP December											
10.0	Mission Life in Years										
				Science Mode @L2 with Comm	Stationkeeping Maneuver	Safe Hold. Not EPS		Momentum Unloading, Peak Power	Launch till Seperation	Repointing (Survival Power)	Cruise Mode/ Insturmrnt Checkout
EPS Load Item Description				watts	watts	watts		watts	watts	watts	watts
Total Power				**4,140.5**	**4,012.2**	**3,580.1**		**3,967.0**	**37.5**	**3,395.8**	**3,963.2**
Time Period Over Which Averaging Is Done For Each Mode (min.)		Contingency									
	Inst Global Contingency	30									
Instruments with Contingency				**3,351.4**	**2,804.6**	**2,804.6**		**2,804.6**	**0.0**	**2,804.6**	**3,351.4**
XMS				1616.0	1280.4	1280.4		1280.4	0.0	1280.4	1616.0
	Contingency	30		484.8	384.1	384.1		384.1	0.0	384.1	484.8
FMA Thermal				877.0	877.0	877.0		877.0	0.0	877.0	877.0
	Contingency	30		263.1	263.1	263.1		263.1	0.0	263.1	263.1
SEP				85.0	0.0	0.0		0.0	0.0	0.0	85.0
	Contingency	30		25.5	0.0	0.0		0.0	0.0	0.0	25.5
N/A				0.0	0.0	0.0		0.0	0.0	0	0.0
	Contingency	30		0.0	0.0	0.0		0.0	0.0	0.0	0.0
N/A				0.0	0.0	0.0		0.0	0.0	0	0.0
	Contingency	30		0.0	0.0	0.0		0.0	0.0	0.0	0.0
N/A				0.0	0.0	0.0		0.0	0.0	0	0.0
	Contingency	30		0.0	0.0	0.0		0.0	0.0	0.0	0.0
Spacecraft Loads with Contingency				**789.1**	**1,207.5**	**775.5**		**1,162.4**	**37.5**	**591.1**	**611.8**
	Spcft Global Contingency	30									
PSE	MAP like (95.4% eff)	190.46		190.5	184.6	165.9		182.9	1.8	156.6	182.4
	Contingency	30		57.1	55.4	49.8		54.9	0.5	47.0	54.7
Electrical - Harness Losses	BGB			7.5	7.3	6.6		7.2	0.1	6.2	7.2
	Contingency	30		2.3	2.2	2.0		2.2	0.0	1.9	2.2
Command & Data Handling	Glenn R.			119.0	119.0	86.0		86.0	22.0	86.0	66.0
	Contingency	30		35.7	35.7	25.8		25.8	6.6	25.8	19.8
Solid State Data Recorder	Na			0.0	0.0	0.0		0.0	0.0	0.0	0.0
	Contingency	30		0.0	0.0	0.0		0.0	0.0	0.0	0.0
Solar Array Drive Motor	NA			0.0	0.0	0.0		0.0	0.0	0.0	0.0
	Contingency	30		0.0	0.0	0.0		0.0	0.0	0.0	0.0
Solar Array Drive Electronics	NA			0.0	0.0	0.0		0.0	0.0	0.0	0.0
	Contingency	30		0.0	0.0	0.0		0.0	0.0	0.0	0.0
Attitude Control	Eric S.			75.0	469.0	57.0		469.0	0.0	57.0	66.0
	Contingency	30		22.5	140.7	17.1		140.7	0.0	17.1	19.8
Thermal	Kim B.			100.0	100.0	232.0		100.0	0.0	100.0	100.0
	Contingency	30		30.0	30.0	69.6		30.0	0.0	30.0	30.0
Propulsion	Richard C.			5.0	5.0	5.0		5.0	5.0	5.0	5.0
	Contingency	30		1.5	1.5	1.5		1.5	1.5	1.5	1.5
Data Systems	Ron V.			110.0	44.0	44.0		44.0	0.0	44.0	44.0
	Contingency	30		33.0	13.2	13.2		13.2	0.0	13.2	13.2

EPC


CONX 2006 w SEP December Mission Over 10 Yr Life With Deployable Panel; 28% Eff Cells; Average Load During Day=4140.487W; Average Load During Night=4012.15386W
Daylight Average Solar Array Power Provided
Daylight Average Solar Array Power Required
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
Mission Time (Days)

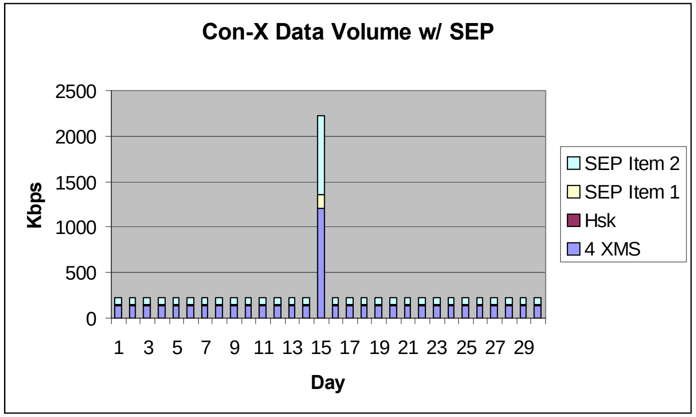
EPS Summary

CONX 2006 w SEP December					Area M^2 or Vol M^3	Total Mass(Kg)
120vDC buss	Dimensions (M)			#		
Solar Array TJGaAs		1.00	21.78	1	21.78	39.63
Lith Ion, Battery 20 Ah 3.29% DOD on Launch	0.24	0.05	0.22	1	0.00	13.87
PSE	1.06	0.28	0.79	1	0.23	50.58
Solar Array Drive				0	0	0.00
Harness spacecraft & solar array				1		0.00
				Total Materials		104.1

EPS Redundancy

- Solar Array is made up of many strings, perhaps more than 40. This inherently leads to graceful degradation and redundancy. This study has added one addition string out of 40 to meet the single fault redundancy.
- Battery redundancy.
  - For this study the only battery requirement is for launch. The launch depth of discharge (DOD) was 10.83% DOD. A smaller battery could easily be baseline, but there may be other requirements for the battery. Other Con-X studies showed a battery need for Momentum Unloading peak power, this scales to be about 20% DOD on this battery. Other requirement may exist.
  - The 18 cell battery should have cell by-pass switches or other battery redundancy forms to provide a single fault redundancy. As the battery ages the effect for a discharge event will cause a larger DOD since the capacity available is decreased with age. Again a larger battery helps. The mass savings for the next smaller battery, a 9ah battery was about 6kg.
  - Redundant bidirectional battery converter (charger/discharger) was not provided since the battery use was only defined for launch. For a redundant Bidirectional converter an additional mass of 4.23kg should be used.
- Power System Electronics has built in redundancy. Redundant solar array regulators, control modules, output module circuits with a buss that should be duel isolated to the output module. The battery bidirectional converter will compensate for a reduced battery voltage by changing its PWM (pulse width modulation) rate and boost to 120 vDC from a lower battery bus voltage.

Data Rates



	w/SEP
Nominal Data Rate	Collection Rate: 33 Kbps*4 + 4 Kbps P/L HSK + 4 Kbps S/C HSK + 13 Kbps S1 + 67 Kbps S2 Downlink Rate: 14 Mbps Contact Time: 34 Mins Data Volume: 28 Gbits
Peak Data Rate	Collection Rate: 300 Kbps*4 + 4 Kbps P/L HSK + 4 Kbps S/C HSK + 150 Kbps S1 + 867 Kbps S2 Downlink Rate: 14 Mbps Contact Time: 111 Mins Data Volume: 93 Gbits
	Recorder Size Req't: 172 Gbits

RF Comm adds 15% CCSDS plus 30% margin to data rates
RF comm designed for a nominal day
Increase contact time for peak days
Dump times are calculated at 10 Mbps for Baseline; 14 Mbps for SEP option
Avionics adds 6% EDAC plus 30% margin to data rates for recorder sizing
Avionics Recorder Sized for 2 peak days (back to back peak days) for possibility of peak day occurring on day 30 in Month 1 and day 1 in Month 2

* Note that Data Volume calculation on peak day uses 25% peak value + 75% nominal value

Data Rate and Storage Analysis

Data Source	Nominal (kbps)	Peak (kbps)
XMS 1	33	300
XMS 2	33	300
XMS 3	33	300
S 4	33	300
SEP1	13	150
SEP2	67	867
H/K Instrument	4	4
H/K Spacecraft	4	4
Total	**140 (212)**	**1,208 (2,225)**

Data recording assumes 6 hrs bright source and 18 hrs non-bright source per J.B.

User Data Storage with 2 days data storage and 100% observing efficiency and 30% margin =

(140 kbps x 60sec/min x 60 min/hr x 18 hr/day x 2 days + 1208 kbps x 60sec/min x 60 min/hr x 6 hrs/day x 2 days) x 1.3 = 156.7 Gbit (19.6 Gbyte)

Baseline has 91.4 Gbit (11.4 Gbytes) data/ 2 day

Recorder Size: 96.9 Gbit (12.1 Gbyte) recorder (assume 6% overhead for Reed Solomon)

(212 kbps x 60sec/min x 60 min/hr x 18 hr/day x 2 days + 2225kbps x 60sec/min x 60 min/hr x 6 hrs/day x 2 days) x 1.3 = 219 Gbit (27.4 Gbytes)

SEP has 160.7 Gbit (20.1 Gbytes) data/ 2 day

Recorder Size: 170.3 GBit (21.3 Gbyte) recorder (assume 6% overhead for Reed Solomon)

RF Comm Downlink

- 10 Mbps downlink rate
- 30 min/day downlink contact always will provide
  - 30min/day x 60sec/min = 1800 sec/day
  - @ 10 Mbps => 18 Gbits/day (2.25 Gbytes/day)
  - Data volume not including CCSDS & Reed Solomon encoding (15%)
    - 18 x 0.87 = 15.6 Gbits/day raw data possible
- For bright source observations (not often on average) than downlink will be increased
- If miss pass than downlink contact will be increased
- Baseline Option (based upon J.B.'s 6 hrs of bright source observation & extra day storage)
  - Raw Data (without CCSDS overhead)
    - 91.4 Gbit/day (11.4 Gbyte/day)
  - Downlink Packets (with CCSDS overhead)
    - 91.4 x 1.15 = 105.1 Gbit/ 2 day (13.1 Gbyte/2 day)
  - Down link time => 2.9 hours @ 10 Mbps
- SEP Option (based upon J.B.'s 6 hrs of bright source observation & extra day storage)
- Raw Data (without CCSDS overhead)
    - 160.7 Gbit/day (20.1 Gbyte/ 2 day)
  - Downlink Packets (with CCSDS overhead)
    - 160.7 x 1.15 = 184.8Gbit/ 2 day (23.1 Gbyte/ 2 day)
  - Down link time => 5.1 hours @ 10 Mbps
- Nominal Data rate only (no missed passes, no bright sources)
  - Raw Data
    - 14.2 Gbit/day
  - Downlink Packets (with CCSDS overhead)
    - 14.2 x 1.15 = 16.33 Gbits/day
  - Downlink time => 27 minutes

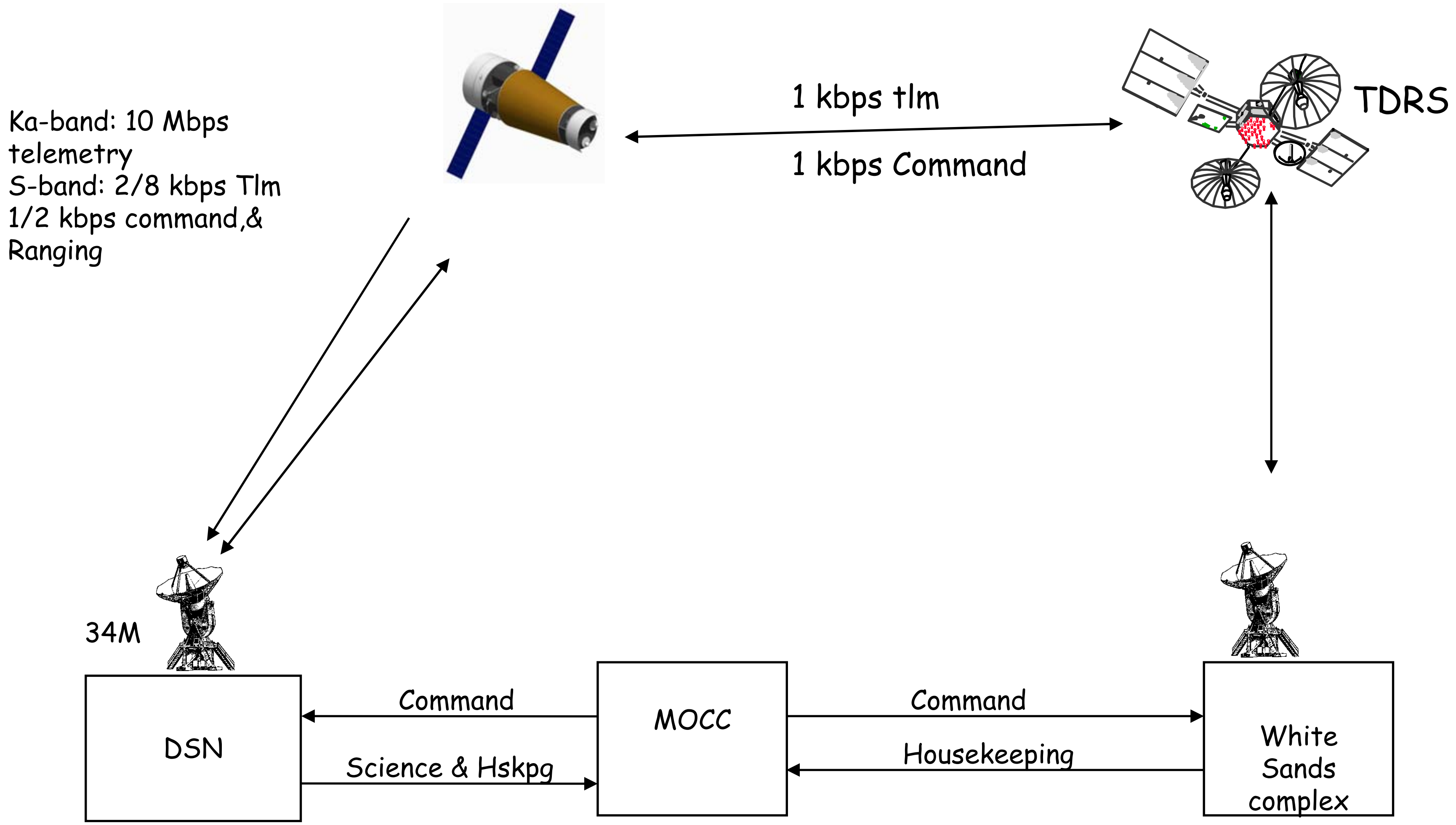
RF Comm Overview

- Ka-Band for science and data dumps via DSN 34 meter
  - Data dumps at 10 Mbps
  - One 34 minute contact required
- S-Band TT&C via HGA to DSN 34 meter
  - 2 kbps command
  - 8 kbps telemetry
- S-Band TT&C via omni to DSN 34 meter
  - 1 kbps command
  - 2 kbps telemetry
- Ranging for orbit determination
- S-Band thru TDRSS for launch and LEO critical events
  - 1 kbps command
  - 1 kbps telemetry
- S/Ka-band communications using DSN 34 m
- Ka-band used for data dumps
  - 0.5 meter S/C antenna
  - 10 watts RF (use TWTAs)
  - 10 Mbps dump rate
  - Data is QPSK and convolutional and R/S encoded
- A 30 minute contact is required every day simultaneous with ranging
  - 95% rain availability is considered
  - Redundancy except for the antenna systems
  - Once a month (average) a 88 minute contact is required for the addition of the peak data

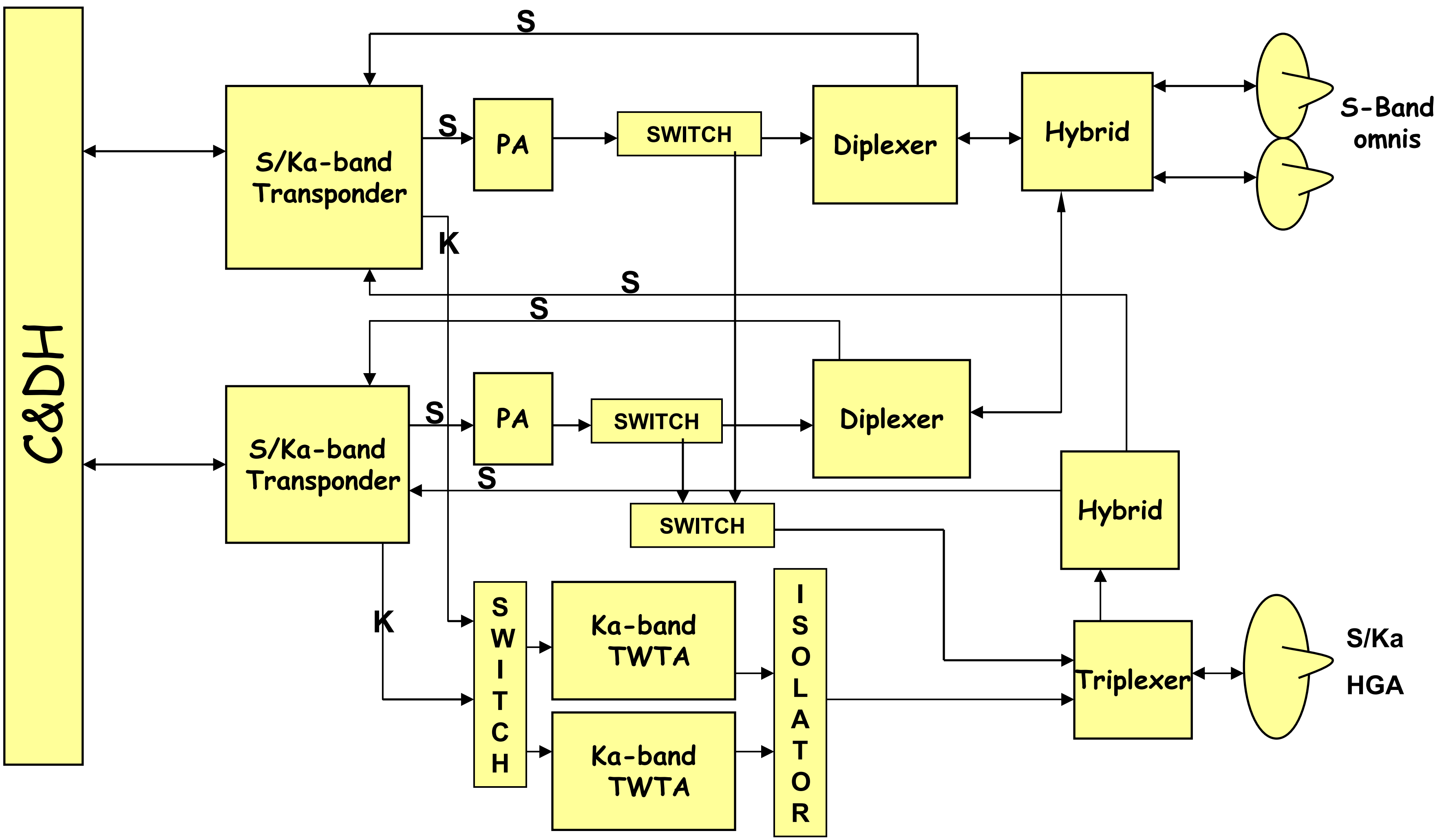
RF Comm Configuration

- S/Ka-band communications using DSN 34 m
- S-Band for TT&C
- 5 watts RF using 5 watt power amplifiers via omnis or the HGA
- Use omnis
  - 2 kbps telemetry
  - 1 kbps command
- Use HGA
  - 8 kbps telemetry
  - 2 kbps command
- Use TDRSS for launch and LEO critical events
  - 1 kbps command
  - 1 kbps telemetry
- Ranging: Two 30 minute contacts per day during transfer orbit and one 30 minute contact per day when on orbit

RF Comm Functional Configuration



RF Comm Block Diagram



DSN Support

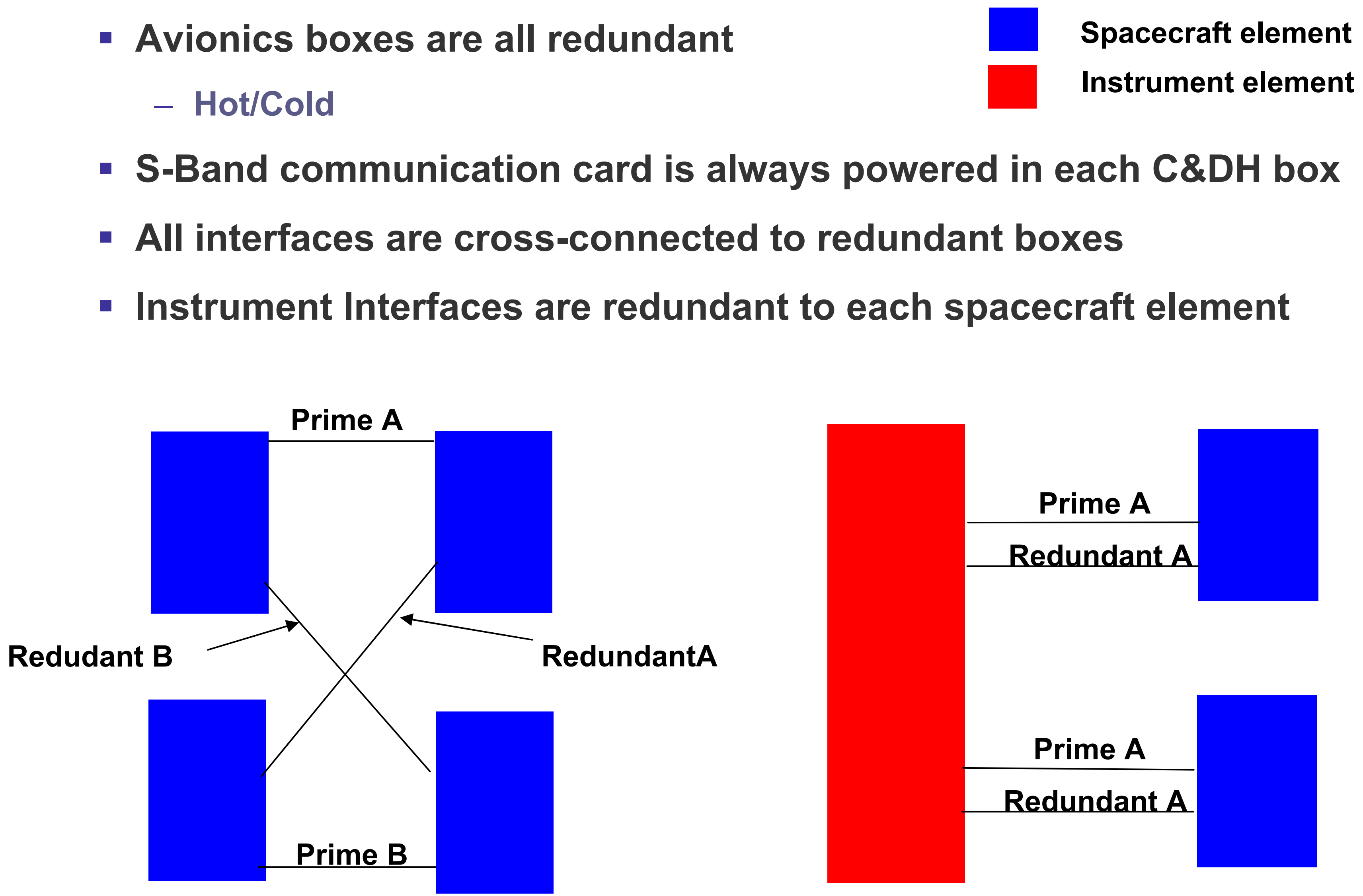
- DSN 34M/Transfer orbit
  - Two 30 minute contacts/day
  - Minimum 8 hour support for mid course corrections
  - 100 days to orbit
- DSN 34M/ Mission orbit
  - One 30 minute contact /day
  - Once a month a 88 minute contact (for peak rate data)
- Pre-pass time: 45 minutes
- Post-pass time: 15 minutes

RF Comm Component Summary

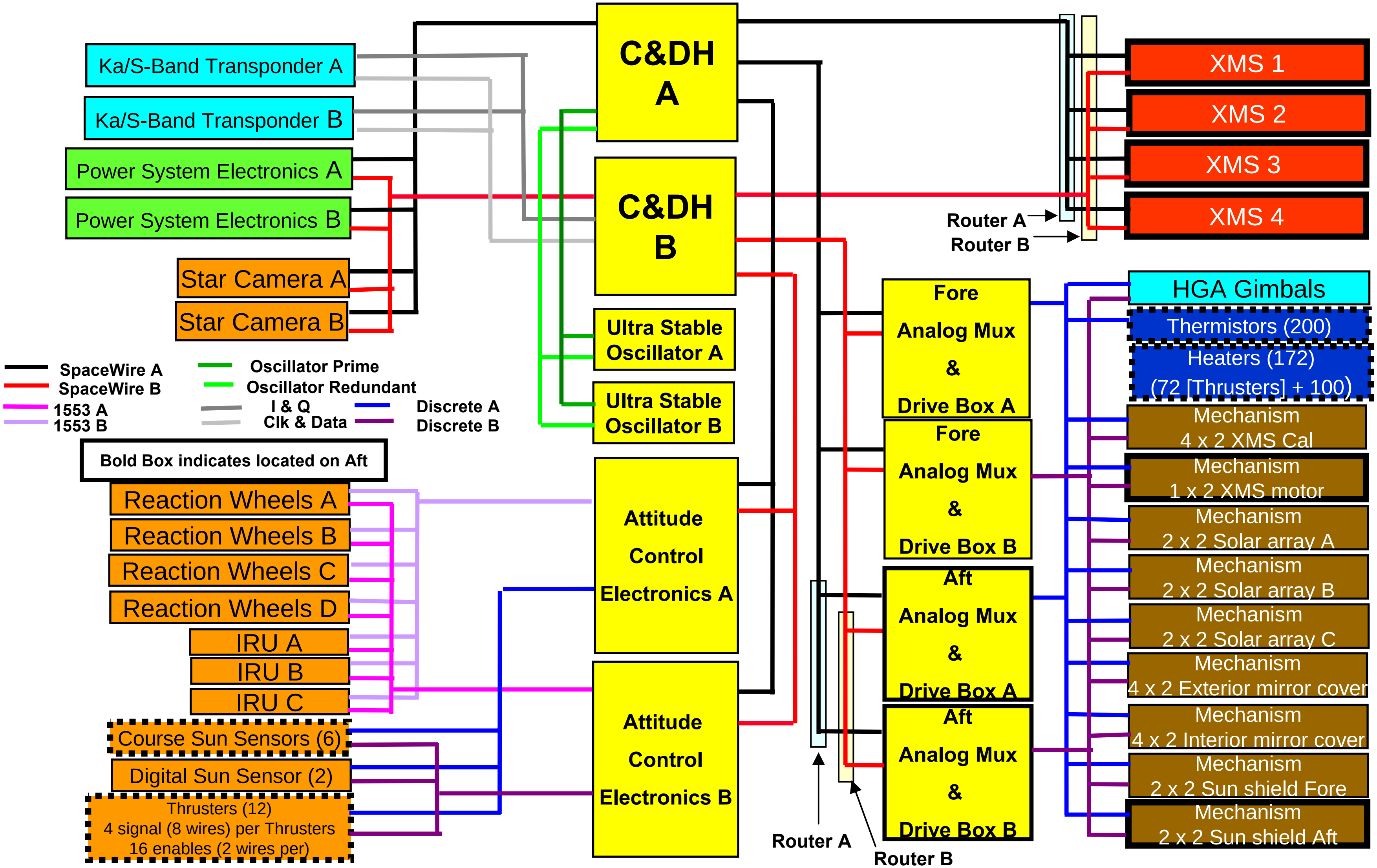
Component	DC Power (watts) pk/avg	Mass (kg)	Cost ($)
*S/Ka Transponder (2)	30/26	6.2	3.2 M
S/Ka Antenna (0.5 Meter) (Antenna only)	30/2	3	1.2 M
10 watt Ka TWTA (2)	30/22	12	2.4 M
5 watt S-band PA (2)	20/2	1	1.0 M
S-band omni (2)	--	2	100 K
Diplexer (2)	--	0.5	100 K
Triplexer	--	1	150 K
Hybrids (2)	--	0.4	100 K
Switches (4)	--	1	160 K
Isolator and cabling, misc	--	3	150 K
TOTALS	110/52	30.1	8.56 M

C&DH Redundancy

- Avionics boxes are all redundant
  - Hot/Cold
- S-Band communication card is always powered in each C&DH box
- All interfaces are cross-connected to redundant boxes
- Instrument Interfaces are redundant to each spacecraft element



Avionics


C&DH A
C&DH B
Ka/S-Band Transponder A
Ka/S-Band Transponder B
Power System Electronics A
Power System Electronics B
Star Camera A
Star Camera B
Ultra Stable Oscillator A
Ultra Stable Oscillator B
SpaceWire A
SpaceWire B
1553 A
1553 B
Oscillator Prime
Oscillator Redundant
I & Q
Clk & Data
Discrete A
Discrete B
Bold Box indicates located on Aft
Reaction Wheels A
Reaction Wheels B
Reaction Wheels C
Reaction Wheels D
IRU A
IRU B
IRU C
Course Sun Sensors (6)
Digital Sun Sensor (2)
Thrusters (12)
4 signal (8 wires) per Thrusters
16 enables (2 wires per)
Attitude Control Electronics A
Attitude Control Electronics B
XMS 1
XMS 2
XMS 3
XMS 4
Router A
Router B
Fore Analog Mux & Drive Box A
Fore Analog Mux & Drive Box B
Aft Analog Mux & Drive Box A
Aft Analog Mux & Drive Box B
HGA Gimbals
Thermistors (200)
Heaters (172)
(72 [Thrusters] + 100)
Mechanism
4 x 2 XMS Cal
Mechanism
1 x 2 XMS motor
Mechanism
2 x 2 Solar array A
Mechanism
2 x 2 Solar array B
Mechanism
2 x 2 Solar array C
Mechanism
4 x 2 Exterior mirror cover
Mechanism
4 x 2 Interior mirror cover
Mechanism
2 x 2 Sun shield Fore
Mechanism
2 x 2 Sun shield Aft
Router A
Router B

Single Board Computer

- BAE RAD 750
- Heritage: SDO
- Specifications:
  - Power PC 750 microprocessor
  - 240 MIPS @ 132 MHz
  - 16 Mbytes SRAM max
  - 4 Mbytes EEPROM
  - cPCI Backplane (not used)
  - SpaceWire interface added
  - 100 krads total dose
  - <1E-10 bit errors per day
  - 6U-160 card size
  - 0.8 kg
  - 7.5 W @ 33 MHz
  - 12 W @ 132 MHz

Communication Card Microprocessor

- General Dynamics RH-CF5208 Coldfire Microprocessor

- Total Dose: 300 krads
- SEL: Immune
- SEU:1E-10 errors/bit-day
- Frequency: 65 MHz max
- MIPS: 60 Dhrystone 2.1 MIPS at 65 MHz
- Temperature: -55 C to +125 C
- Power: <1.6 watts at 65 MHz, 3.3 V
- 8 kByte SRAM
- DMA Controller
- Dual UART
- Dual 16 bit Timers
- DRAM Controller
- Fully static 3.3 V operation
- 256 pin CQFP Package

C&DH Storage Summary

- Baseline
  - 96.9 Gbit (12.1 Gbyte) SDRAM board
  - Includes Reed Solomon protection on SDRAM
    - Transparent to downlink (not included in downlink stream)
  - 2 days storage
  - Each day has 6 hours peak and 18 hours nominal
    - Worst case
  - 1 board in each C&DH
- SEP Option
  - 170.3 Gbit (21.3 Gbyte) SDRAM board
  - Includes Reed Solomon protection on SDRAM
    - Transparent to downlink (not included in downlink stream)
  - 2 days storage
  - Each day has 6 hours peak and 18 hours nominal
    - Worst case
  - 2 board in each C&DH
    - One board 18 Gbyte
    - One board 3.3 Gbyte

Avionics Mass & Power

Component	Quantity	Mass (kg)		Power (W)			
		Item	Total	Launch	Cruise	Safehold	Science
C&DH	2	15	30	26	26	4	67
Attitude Control Electronics	2	12	24	0	0	22	22
Fore Analog Mux & Driver Box	2	9	18	0	4	0	8
Aft Analog Mux & Driver Box	2	9	18	0	4	0	8
Router	2	1.8	3.6	0	6	0	6
Ultra Stable Oscillator	2	0.4	0.8	4	4	4	4
TOTAL			**94.4**	**30**	**44**	**30**	**115**

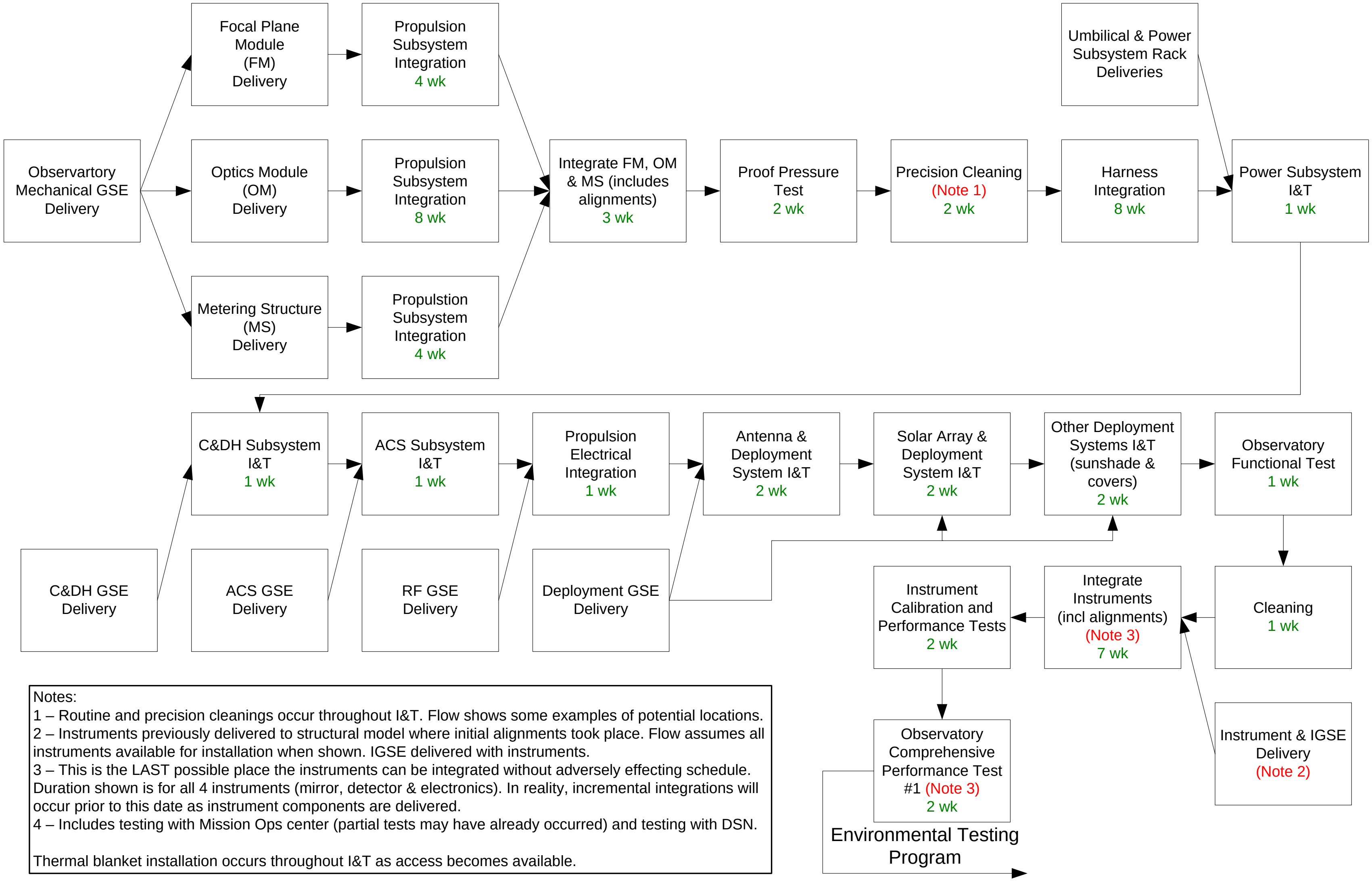
I&T Approach (assumptions)

- FMA's, XMS's and associated electronics delivered flight-qualified for I&T including end-to-end testing with x-rays.
  - Bounds work, end-to-end test not possible for full up observatory w/ Xrays.
- I&T must accommodate delivery of FMA's and XMS's in any order.
  - Realism
- XMS can be operated in ambient to enable functional testing and CPT's w/o need for vacuum chamber.
  - Requiring functional testing to occur in only vacuum restricts testing, greatly increases budget and schedule. Eliminates need to break chamber for each anomaly, saves cost and schedule.
- Mass simulators exist for all components and are high fidelity at interfaces.
  - Used in conjunction with qual structure, allows practice for alignments w/ reduced contam risk. Enables early modal surveys and verification of structure models
- S/C simulators provided to instrument team.
  - Enables development and troubleshooting of procedures and software prior to delivery.

I&T Approach (assumptions cont'd)

- Rigorous contamination control including special filtration, constant mirror purge, continuous real time monitoring (SAW's), scheduled cleanings and black light inspections.
  - Preserves science integrity. Must be considered in selection, configuration and operation of facilities, cost driver, schedule driver.
- X-ray point source GSE used to monitor contamination in optical path, especially FMA's.
  - Gives realistic measurement of science degradation, indicate contam event.
- Cabling between FPM and OE will be run inside shielded conduit attached to the outside of the metering structure
  - Enables space charging protection, creates faraday cage, simplifies installation and repair of wiring, accommodates updates and changes easily.
- Final S/C environmental testing performed with no mass simulators, mockups, protoflight units etc.
  - Enables Test as you fly, demonstrates self compatibility, more important since end-to-end science testing not possible.
- Structural verification model (2nd flight like struture) built and used for modal surveys, to verify structure models, to practice alignments w/o risking contamination on flight structure.
  - Reduces Risk

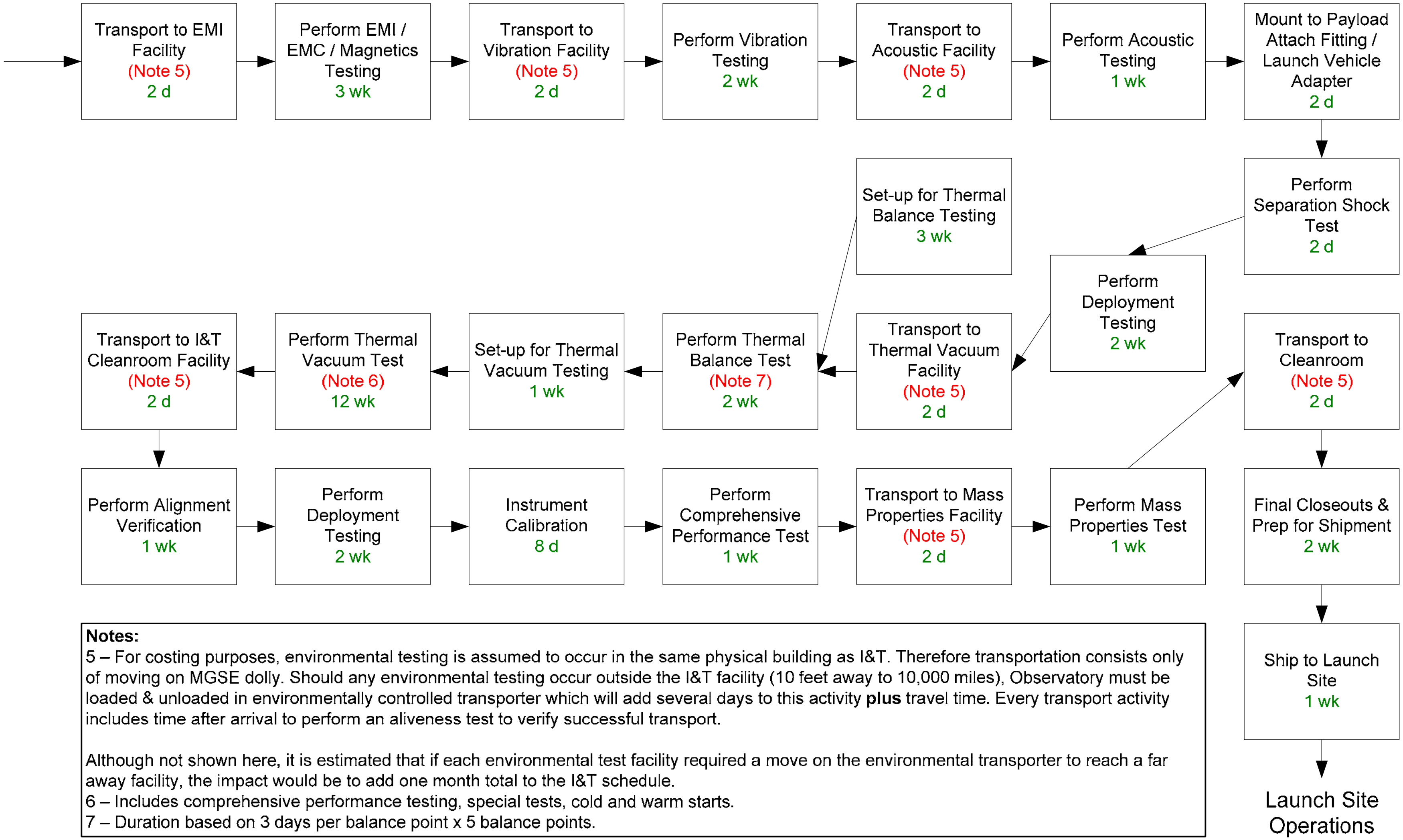
Integration and Test Flow



Notes:
1 – Routine and precision cleanings occur throughout I&T. Flow shows some examples of potential locations.
2 – Instruments previously delivered to structural model where initial alignments took place. Flow assumes all instruments available for installation when shown. IGSE delivered with instruments.
3 – This is the LAST possible place the instruments can be integrated without adversely effecting schedule. Duration shown is for all 4 instruments (mirror, detector & electronics). In reality, incremental integrations will occur prior to this date as instrument components are delivered.
4 – Includes testing with Mission Ops center (partial tests may have already occurred) and testing with DSN.

Thermal blanket installation occurs throughout I&T as access becomes available.

Integration and Test Flow (cont'd)



Notes:
5 – For costing purposes, environmental testing is assumed to occur in the same physical building as I&T. Therefore transportation consists only of moving on MGSE dolly. Should any environmental testing occur outside the I&T facility (10 feet away to 10,000 miles), Observatory must be loaded & unloaded in environmentally controlled transporter which will add several days to this activity **plus** travel time. Every transport activity includes time after arrival to perform an aliveness test to verify successful transport.

Although not shown here, it is estimated that if each environmental test facility required a move on the environmental transporter to reach a far away facility, the impact would be to add one month total to the I&T schedule.
6 – Includes comprehensive performance testing, special tests, cold and warm starts.
7 – Duration based on 3 days per balance point x 5 balance points.

Integration and Test Flow (cont'd)

I&T GSE

Equipment	Purpose	Provider
Electrical Ground Support Equipment (EGSE)	Electrical control and testing of the S/C (i.e. Umbilical console)	Electrical Subsystem
Spacecraft Ground Support Equipment (SGSE)	**S/C command, control, and telemetry** **(i.e. ASIST workstations, front end data processing & distribution, archiving, other IT equipment)**	**I&T**
Mechanical Ground Support Equipment (MGSE)	Ground handling and transportation (i.e. Dollies, slings, access scaffolding, rotation fixtures, environmentally controlled transporter, etc.)	Mechanical Subsystem
Power GSE	Support, control and/or simulate power system components (i.e. Solar array simulator, battery simulator, battery AC, battery GSE)	Power Subsystem
Alignment Ground Support Equipment (AGSE)	Aligning spacecraft components and instrument. (i.e. Tooling bars, theodolites, levels, tilt sensors, dihedral reference mirrors, etc.)	Optical Branch Support
I&T Ground Support Equipment (I&T GSE)	**Assist in execution of I&T (i.e. Oscilloscopes, meters, current probes, break out boxes ESD protective equipment, IT equipment, etc.)**	**I&T**

NOTE: Substantial amounts of GSE are required to support the integration effort. Much of this equipment will be developed and used at the subsystem level and be delivered with the flight hardware to I&T. Other equipment will be developed specifically for I&T use. Only GSE identified in this table as being provided by I&T is included in the I&T costs. The costs for all other GSE are assumed to be carried by the group identified in the column marked “Provider”. The costs and development schedule of this equipment is not trivial. This list is not meant to be exhaustive or complete.

Master Equipment List – w/o SEP

SPACECRAFT BUS	Quantity	Unit Mass	Estimate	Margin	Estimate with Margin
Attitude Control System			**67.7 kg**	**30%**	**88.0 kg**
Adcole Coarse Sun Sensors	6	0.2 kg	1.0 kg	30%	1.2 kg
Fine Sun Sensors	2	1.4 kg	2.7 kg	30%	3.5 kg
Ball CT-602 Star Trackers	3	5.4 kg	16.2 kg	30%	21.1 kg
Litton SIRU	1	5.4 kg	5.4 kg	30%	7.1 kg
Honeywell HR14 (75)	4	10.6 kg	42.4 kg	30%	55.1 kg
Avionics			**99.6 kg**	**30%**	**129.4 kg**
Single Board Computer	2	0.8 kg	1.6 kg	30%	2.1 kg
Ka/S Band Downlink	2	1.5 kg	3.1 kg	30%	4.0 kg
Bus Interface Card	2	1.0 kg	2.0 kg	30%	2.6 kg
Backplane	2	1.5 kg	3.0 kg	30%	3.9 kg
Chassis	2	6.0 kg	12.0 kg	30%	15.6 kg
Low Voltage Power Converter	2	1.6 kg	3.2 kg	30%	4.2 kg
SDRAM Memory Card (100 Gbit)	4	1.3 kg	5.2 kg	30%	6.8 kg
USO	2	0.8 kg	1.6 kg	30%	2.1 kg
ACE Coldfire Processor	2	1.2 kg	2.4 kg	30%	3.1 kg
ACE Bus I/F Card	2	1.4 kg	2.8 kg	30%	3.6 kg
ACE Thruster Driver Card	2	1.5 kg	3.0 kg	30%	3.9 kg
ACE Analog Sensor Card	2	1.5 kg	3.0 kg	30%	3.9 kg
ACE Low Voltage Power Converter	2	1.8 kg	3.6 kg	30%	4.7 kg
ACE Chassis Box	2	4.0 kg	8.0 kg	30%	10.4 kg
ACE Backplane	2	0.8 kg	1.5 kg	30%	2.0 kg
Analog Mux Bus I/F Card	4	1.6 kg	6.4 kg	30%	8.3 kg
Analog Mux Mechanism Drive Card	4	1.5 kg	6.0 kg	30%	7.8 kg
Analog Mux Thermistor Analog Card	4	1.5 kg	6.0 kg	30%	7.8 kg
Analog Mux Chassis Box	4	4.0 kg	16.0 kg	30%	20.8 kg
Analog Mux Backplane	4	0.5 kg	2.0 kg	30%	2.6 kg
Router Box Bus I/F Card	2	1.6 kg	3.2 kg	30%	4.2 kg
Router Box Chassis Box	2	2.0 kg	4.0 kg	30%	5.2 kg
Electrical Power			**100.2 kg**	**30%**	**130.3 kg**
Solar Array Triple Junction GaAs Cells	1	36.4 kg	36.4 kg	30%	47.3 kg
Lithium Ion Battery (20 Amp-hr; 17 cells)	1	13.9 kg	13.9 kg	30%	18.0 kg
PSE	1	50.0 kg	50.0 kg	30%	64.9 kg
Harness			**185.0 kg**	**30%**	**240.5 kg**
Harness	NA	NA	185.0 kg	30%	240.5 kg
Propulsion			**62.8 kg**	**30%**	**81.6 kg**
Hz Tank PSI 80364-1	3	5.7 kg	17.0 kg	30%	22.1 kg
NTO Tank PSI 80353-1	3	3.9 kg	11.6 kg	30%	15.1 kg
CPOV He Tank PSI 80400-1	1	10.0 kg	10.0 kg	30%	13.0 kg
AMPAC 22 N BiProp Thrusters	12	0.7 kg	8.9 kg	30%	11.5 kg
Mu He Regulator	1	1.3 kg	1.3 kg	30%	1.6 kg
Manifold, valves, filters, PT's	1	14.1 kg	14.1 kg	30%	18.3 kg

Structural/Mechanical			**1129.2 kg**	30%	1468.0 kg
Isogrid Metering Structure	1	408.0 kg	408.0 kg	30%	530.4 kg
Detector Deck	1	65.2 kg	65.2 kg	30%	84.8 kg
Detector Sun Shade	1	2.0 kg	2.0 kg	30%	2.6 kg
Baffles/Thrust Tubes	4	24.2 kg	96.8 kg	30%	125.8 kg
Mirror Covers	8	4.4 kg	35.2 kg	30%	45.8 kg
Mirror Sunshade	1	2.0 kg	2.0 kg	30%	2.6 kg
Deployable S/A Panels	6	11.4 kg	68.4 kg	30%	88.9 kg
Yokes	2	2.2 kg	4.4 kg	30%	5.7 kg
Launch Lock	6	1.3 kg	7.8 kg	30%	10.1 kg
Body Mounted S/A Panels	5	7.7 kg	38.5 kg	30%	50.1 kg
Antenna Mast	1	0.7 kg	0.7 kg	30%	0.9 kg
Antenna Gimbal	1	5.3 kg	5.3 kg	30%	6.9 kg
Thermal Radiator Panel	1	18.3 kg	18.3 kg	30%	23.8 kg
Mechanisms	12	1.0 kg	12.0 kg	30%	15.6 kg
Bus Deck 1	1	52.3 kg	52.3 kg	30%	68.0 kg
Bus Deck 2	1	128.1 kg	128.1 kg	30%	166.5 kg
XMS Component Radiator Panel	4	9.3 kg	37.2 kg	30%	48.4 kg
XMS Deck Beams	6	3.4 kg	20.4 kg	30%	26.5 kg
Baffle Plate A	1	39.0 kg	39.0 kg	30%	50.7 kg
Baffle Plate B	1	28.0 kg	28.0 kg	30%	36.4 kg
Counter Weights	1	32.1 kg	32.1 kg	30%	41.7 kg
Clips, Fasteners, Etc.	1	27.5 kg	27.5 kg	30%	35.8 kg
Thermal			**177.6 kg**	**30%**	**230.9 kg**
Axial Groove Ammonia Fixed Conductance	6	3.0 kg	18.0 kg	30%	23.4 kg
MLI	1	52.0 kg	52.0 kg	30%	67.6 kg
Thermofoil Heaters - Prop sys, S/C Electric	180	0.1 kg	9.0 kg	30%	11.7 kg
General Coatings	14	0.3 kg	3.5 kg	30%	4.6 kg
Thermistor	200	0.0 kg	5.0 kg	30%	6.5 kg
Thermostats	180	0.0 kg	4.5 kg	30%	5.9 kg
Misc. Thermal H/W - Closeout vents	10	2.0 kg	20.0 kg	30%	26.0 kg
Heat Pipe Radiator Panel	1	13.6 kg	13.6 kg	30%	17.7 kg
Radiator	1	4.0 kg	4.0 kg	30%	5.2 kg
Collimator P/L capton film heaters	2000	0.0 kg	30.0 kg	30%	39.0 kg
Loop heat pipe - mirror assembly	4	4.5 kg	18.0 kg	30%	23.4 kg
Communications			**30.1 kg**	**30%**	**39.1 kg**
DSN S/Ka Band Transmitter	2	3.1 kg	6.2 kg	30%	8.1 kg
HGA - 0.5 m	1	3.0 kg	3.0 kg	30%	3.9 kg
10 W TWTA	2	6.0 kg	12.0 kg	30%	15.6 kg
Omni antenna	2	1.0 kg	2.0 kg	30%	2.6 kg
Diplexer	2	0.3 kg	0.5 kg	30%	0.7 kg
Triplexer	1	1.0 kg	1.0 kg	30%	1.3 kg
Hybrid	2	0.2 kg	0.4 kg	30%	0.5 kg
Switch	4	0.3 kg	1.0 kg	30%	1.3 kg
Cabling, Misc.	1	3.0 kg	3.0 kg	30%	3.9 kg
S-band 5 W power amplifier	2	0.5 kg	1.0 kg	30%	1.3 kg
Mechanisms			**146.6 kg**	**30%**	**190.6 kg**
Mechanisms			146.6 kg	30%	190.6 kg
Spacecraft Bus Total			**1998.8 kg**	**30%**	**2598.5 kg**

BACKUP MATERIAL
-
PAYLOAD ACCOMMODATION REQUIREMENTS

SXT Mirror Parameters

Parameter	Description
Number of FMA's	4
Mirror Design	Segmented Wolter I
Focal length	10.0 m
Diameter outermost mirror shell	1.3 m
Diameter innermost mirror shell	0.3 m
Mirror segment length (primary or secondary)	20 cm
Number of modules per mirror	5 (inner); 10 (outer)
Number of nested mirror shells	68 (inner); 95 (outer)
Number of mirror segments	2600 per FMA, 10,400 total (163 unique sizes)
Mirror Segment substrate material	Thermally formed glass
Mirror segment thickness	0.44 ± 0.02 mm
Largest segment surface area	0.08 m^2
Substrate density	2.5 g/cm^3
X-ray reflecting surface	Iridium
Mirror angular resolution	<15" HPD (<5" HPD goal)
FMA overall mechanical envelope	1.36 m dia x 1.50 m
Module housing composition	Titanium alloy, CTE-matched to substrate
Module support structure	Composite
Total FMA Mass (ea)	393 kg

FMA Interface Requirements

- Dimensions
  - 4 assemblies, each 1.36m in diameter x 1.5m tall (TBR)
- Mounting
  - The XMS detectors need to be 10.00 m from the node of the FMA mirror node (midpoint between the primary and secondary mirror segments).
  - (The XMS detector is ~ 15cm (TBR) from the XMS mounting plane)
- Mass = 393 kg each
- Power
  - Heater Power (max of 280W/mirror)
    - Applied to pre/post collimators & structure as necessary to meet stability requirement
- Thermal
  - Operating Temperature = +20 deg C
  - Survival Temperature = +10 to +30 deg C
  - Gradients / Stability / Isolation => max gradient = 1 deg C, stability = +/- 0.5 deg. C (single mirror)
- Contamination Control / Purge
  - Very sensitive to particulates and sensitive to volatiles (particularly hydrocarbons)
- No direct sunlight permitted on mirrors (Sun Shade?)
- Alignment
  - Focus: XMS to FMA alignment to within +/- 1 mm (TBR)
  - Off-axis: XMS to FMA alignment to within +/- 0.25 mm (TBR)
  - SXT to SXT co-alignment to within 10 arcsecond (TBR)

XMS Instrument System Components List

- Cryostat Assembly (includes detector)
  - Optical Blocking Filters, Microcalorimeter Detector array, Anti-coincidence Detector, 4-stage Continuous ADR)
- Cryocooler
  - Cold head (located in Cryostat)
  - Condenser
  - Compressor
  - Heat pipes
  - Radiator
- Support Structure
  - Stewart platform mount
  - 3 DOF Mechanism (Focus and off-axis: X and Y)
- Electronics
  - SQUID MUX Control and Readout Electronics (analog)
  - Signal Processing Electronics (digital)
  - Low Voltage Power Supply
  - ADR Control/Housekeeping Electronics
  - Cryocooler Control Electronics

XMS Performance Requirements

XMS Per	
Bandpass	0.3 - 10keV
Spectral Resolving Power	1500 @ 6keV
Angular resolution	$\leq$ 5 arcsec
Field of View	2.5 arcmin
Derived Detector Requirements	
Pixel Size	0.250 x 0.250 mm
Number of Pixels	1024
Operating Temperature	50mK

XMS Interface/Accommodation Requirements

XMS Dimensions (per XMS), cm					
Item	Length	Width	Height	Diameter	Proximity to Cryostat
XMS Aperture baffle			20 (TBR)	TBD	Entrance Aperture
Cryostat Assembly			100	75	-
Cryocooler (compressor & condenser)			44	20	Aft end
Cryocooler Heat Pipes	As required				As required
Cryocooler Radiator(s)	As required				As required
(2) SQUID MUX Control and Readout Electronics	30	30	20		<2m (as close as possible)
(2) Signal Processing Electronics	30	30	20		<3m
Low Voltage Power Supply	30	30	20		<3m
ADR Control/Housekeeping Electronics	30	30	20		<3m
(2) Cryocooler Control Electronics	24.5	12	18.5		<3m

- Mounting
  - XMS is sensitive to microphonic vibration – some isolation may be required if vibration sources are nearby
  - SQUID MUX Control and Readout Electronics Location limits wrt detectors
    - wire length so that ≤ 50 ohms max/22 AWG (1-2m TBR)

XMS Interface Requirements (cont'd)

XMS Masses, kg (numbers are for each XMS)		
Item	Mass (ea)	Mass (per XMS)
Cryostat	89.6	89.6
Stewart platform mount & mechanisms	12	12
Cryocooler	19	19
SQUID MUX Control and Readout Electronics (total of 2)	7.9	15.8
Signal Processing Electronics (total of 2)	6.6	13.2
Low Voltage Power Supply	1.5	1.5
ADR Control/Housekeeping Electronics	15	15
Cryocooler Control Electronics (total of 2)	4.2	8.4
External Harnesses	3	3
XMS Total		177.5

- The XMS cryostats require shading from sunlight – design TBD

XMS Interface Requirements (cont'd)

XMS Power, W (numbers are for each XMS)				
Item	Avg.	Peak	Stand-by	Safe-hold
Cryocooler [to lift 20 mW at 4.5K] Cryocooler [to lift 30 mW at 4.5K]	170 250 (BOL)	250 300 (EOL)	15 (electronics only)	Shut down for safehold poses restart risk, emergency shut down only
SQUID MUX Control and readout Electronics (total of 2)	48	48	48	0
Signal Processing Electronics (total of 2)	36	82	35	0
Low Voltage Power Supply	20.1	34.5	12.45	0
ADR Control/Housekeeping Electronics	50	100	n/a	Controlled ramp-down(s)
Heater Power	TBD	TBD	TBD	TBD

XMS Interface Requirements (cont'd)

XMS Thermal Requirements			
Item	Operating	Survival	Stability
Cryostat Shell (operating point expected in this range)	80 K – 100K	< TBD	5/day
SQUID MUX Control and readout Electronics	-20 to +50C	-30 to +70C	2 C/hour
Signal Processing Electronics	-20 to +50C	-30 to +70C	None
Low Voltage Power Supply	+10 to +40C	-30 to +70C	None
ADR Control/Housekeeping Electronics	+10 to +40C	-30 to +70C	None
Cryocooler Radiator	+7 to +27C	None	5 C/day

SEP Accommodation Requirements 1/2

SEP Part 1 of 2			
	Optic	Detector	Electronics
Location	Optical bench, center or outside SXTs, but as close to center as possible	Focal plane, boresight aligned to optic	Focal plane, nearby detector
Volume	Consider as point masses		
Mass	70 kg	30 kg	
Power (peak)	n/a	15W	
Power (avg)	n/a	15W	
Data rate (peak)	n/a	150 kbps	
Data rate (avg)	n/a	13 kbps	
Thermal (operating)	20 +/- 0.5C	-20 to -5C (Detector) -50 to +10C (housing)	-30 to +30C
Thermal (survival)	+10 to +30C	-40 to +40 C (detector) -50 to +40C (housing)	-50 to +30C

SEP Accommodation Requirements 2/2

SEP Part 2 of 2			
	Optic	Detector	Electronics
Location	Between optical bench and focal plane at 1/3 point – closer to focal plane, within one of the SXT beams	Focal plane, between the XMS detector and the center of the focal plane	Focal plane, nearby the detector
Volume	Consider as point masses		
Mass	50 kg	50 kg	
Power (peak)	n/a	30W	
Power (avg)	n/a	30W	
Data rate (peak)	n/a	867 kbps	
Data rate (avg)	n/a	67 kbps	
Thermal (operating)	20 +/- 0.5C	-80 to -60C	-5 to +25C
Thermal (survival)	+10 to +30C	-100 to +30 C	-65 to +40C

Maximum Impact Case SEP Point Masses